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PROTOTYPE ENVIRONMENTAL DIGITAL DATA FOR MATERIEL DESIGN, TESTING, AND EVALUATION

by

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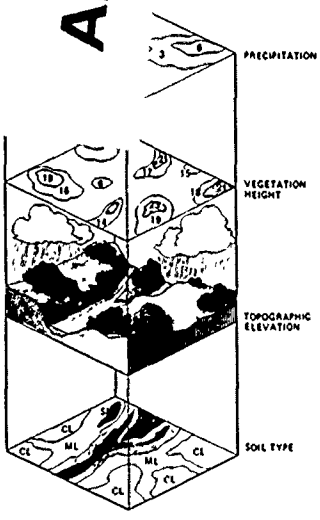

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(cont from pg 1) A computerized simulation is used for performance prediction.

A prototype environmental data set was developed for a single geographic area. This data set will provide realistic digital terrain and environmental factors to materiel designers and developers for use with simulation performance models. Factor categories include topography, vegetation, surface and subsurface composition, hydrologic features, cultural features, climate, weather, and obscurants.

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PREFACE

A The prototype environmental data set was devised to provide materiel developers with information on terrain and environmental factors that affect the design, development, and testing of Army materiel (e.g., mines, munitions/weapons, bridges, vehicles, sensors, etc.). This work was conducted for Headquarters, US Army Corps of Engineers (HQUSACE), under Department of the Army Project No. 4A762719AT40. The HQUSACE Technical Monitor was LTC Ted Scott.

(To front, pg. 4)

Preparation of the prototype data set was sponsored by the Environmental Standards for Materiel Design Group, which includes representatives from the US Army Engineer Topographic Laboratory, US Army Atmospheric Sciences Laboratory, US Army Cold Regions Research and Engineering Laboratory, and US Army Engineer Waterways Experiment Station (WES). The WES was responsible for the design and compilation of the data set. The other Laboratories provided data for inclusion in the data set.

This document was prepared by Ms. E. May Causey and Mr. Harold W. West, of the Environmental Analysis Group (EAG), Environmental Laboratory (EL), WES, under the direct supervision of Mr. West, Chief, EAG, and the general supervision of Dr. Victor E. LaGarde III, Chief, Environmental Systems Division, EL, and Dr. John Harrison, Chief, EL. This report was edited by Ms. Lee T. Byrne, Information Technology Laboratory, WES.

Commander and Director of WES during publication of this report was COL Larry B. Fulton, EN. Dr. Robert W. Whalin was Technical Director.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	2.54	centimetres

PROTOTYPE ENVIRONMENTAL DIGITAL DATA FOR MATERIEL DESIGN, TESTING, AND EVALUATION

PART I: INTRODUCTION

Background

1. The US Army materiel developers need effective guidance to determine the environmental conditions under which new materiel must operate. In the past, AR 70-38, "RDT&E of Materiel, for Extreme Climatic Conditions (1979)," provided the Research, Development, Test, and Evaluation (RDT&E) community limited climatic information about extreme climatic conditions for use in fielding materiel.

2. In 1985, the Executive Committee of the Airland Battlefield Environment (ALBE) Thrust made a fundamental decision that AR 70-38 no longer met the needs of the modern development community and should be revised. To implement this revision of environmental standards for the US Army, the ALBE Executive Committee established the Environmental Standards for Materiel Design Group (ESMDG), which had the responsibility of planning, executing, coordinating, and overseeing the development of environmental standards for atmospheric obscurants, climate, and terrain.

3. In addition to modifying AR 70-38, the ESMDG decided to develop a prototype environmental data set for one area in central West Germany. This data set was to be in digital format so that it could be used with existing and future analytical performance prediction models that simulate materiel systems. The prototype would provide users with a data set for evaluation. Comments and suggestions would then be used as a guide for compiling additional data sets if such are funded by Department of Defense agencies responsible for materiel development.

4. The US Army materiel developers need quantitative terrain and environmental data on different geographic regions. Determining which environmental factors to use in the prototype data set was a somewhat arbitrary and by no means comprehensive decision. Availability of data was a primary consideration. Those terrain and environmental factors selected cover a number of criteria affecting the design, evaluation, and operation of US Army materiel. Factor categories include topography, vegetation, surface and

subsurface composition, hydrologic features, cultural features, climate, weather, and obscurants.

Purpose

5. The purpose of this study was to compile a high-resolution prototype digital data set on a single geographic area, Figure 1, (one 1:50,000 map sheet size area) for use in the design, testing, and evaluation of materiel. A false color composite of the Hunfeld area for 10 October 1986 was obtained by the thematic mapper sensor on board the Landsat Satellite (Plate 1). Additional data on selected sites or small subareas within the 1:50,000-scale map sheet area would also be included providing realistic data at a greater level of resolution. The overall data set would then be used with selected materiel simulation models to determine its adequacy for materiel developers and evaluators.

PART II: TERRAIN DATA DESCRIPTIONS

6. To provide a list of important environmental factors, an assessment was made of nine categories of materiels, which include:

a. Mine systems (conventional, scatterable, and wide area (smart))

b. Vehicle systems (tracked, wheeled, and robotic).

c. Sensor systems (infrared, millimetre-wave radar, seismic, acoustic, magnetic, pressure, and trip wire).

d. Bridging systems (fixed, floating, and assault tactical).

e. Munition systems (point detonating, variable-time, and chemical fuse systems and other sensor-based systems included in c).

f. Direct-fire weapon systems (target detection, guidance, identification, and classification functions).

g. Top-attack weapon systems (tracking, acquisition, aiming, and weapon warhead firing functions).

h. Communication systems (radio, microwave, short wave).

i. Aircraft systems (fixed and rotary).

7. Matrices of 88 of these important factors were constructed during the assessment of the materiel (Appendix A). Data constraints and time prevented including all 88 factors in the ESMDG data set. Table 1 lists the terrain and environmental factors comprising the data set as of June 1988.

8. Data were compiled using three different levels of resolution: (a) areal factor data have a resolution of 30 m, (b) linear factor data have a 10-m grid resolution, and (c) site-specific ground truth data have different levels of resolution. Figure 2 illustrates the layout of the data sets at 30-m grid resolution. With the exception of the grid size, layout for the 10- and 2.5-m gridded data is the same.

9. Information used for compiling the prototype data set was obtained from various agencies and sources; some of the terrain factors were developed specifically for this study. Brief descriptions of the methodologies applied to interpolate source data for specific terrain factors are given where appropriate. Each of the data categories is discussed in the following paragraphs.

Areal and Linear Factor Data

Topographic factors

10. Elevation, slope magnitude, and slope aspect. Topographic elevation data were obtained by digitizing the contours from the 1:50,000-scale Hunfeld quadrangle map (L5324) and then converting them into a 30-m grid (raster) format. Special software was used to grid the digitized elevation data. A computer-drawn plot of the terrain surface elevations within the Hunfeld quadrangle (Figure 3) was constructed using the 100-m gridded elevation data from an earlier US Army Engineer Waterways Experiment Station (WES) study (West, Krivitizky, and Randolph 1980). Slope magnitude data were calculated from the gridded elevation data using the program SLOPEMAP (Struve 1977). Aspect was calculated using the Geographical Resources Analysis Support System (GRASS) software (US Army Construction Engineering Research Laboratory 1988).

11. Roughness and obstacle factors. Surface roughness, obstacle types, obstacle spacing, obstacle length, obstacle base width, obstacle vertical magnitude, and obstacle approach angle (Table 1) were prepared for the earlier WES study (West, Krivitizky, and Randolph 1980) and were already in digital format. Data collection and preparation procedures for these factors are discussed in West, Krivitizky, and Randolph (1980). Grid resolution is 30 m for all topographic factors.

Surface composition factors

12. Data on soil types, soil permeability, soil layer depths (for three layers), compression wave velocity (for each soil layer), shear wave velocity (for each soil layer), and depth to water table were mapped using ground truth data, photography, and knowledge of the area (Dornbusch 1987). These factors were set in map format, digitized, and gridded at a 30-m resolution using standard WES software.

13. Soil types. Soil type data were developed from topographic and geologic maps and from field samples taken at various locations in the Hunfeld area. Geologic maps were examined to determine parent material. Specific soil site profiles were examined to determine consistency of ground truth data with soil associations. Soil units from a general soils map of the state of Hessen were also compared with the more detailed associations to verify mapping units. Plate 2 is a graphical display of the soil types occurring in the Hunfeld quadrangle area.

14. Soil layer depths. Three layers of soil were identified for the Hunfeld quadrangle area: the surface soils, the subsurface soil lying between the surface and parent materials, and the parent material. Soil layers are generally identified in terms of variations in texture, consistency, organic content, and density. Surface features including bodies of water and areas of rock outcrops were excluded from soil layer determination as were urban areas and cultural features of sufficient size to justify mapping. Soil layers were delineated according to their seismic wave velocities. Because of limited seismic refraction data, depths greater than 9 m were not considered.

15. Soil permeability. The permeability data were based on information from the US Department of Agriculture Soil Survey Reports for counties in the United States that are geographically and climatically similar to the Hunfeld area. Critical parameters used for determining analogy of soils were texture, density, and porosity. Permeability values for analogous US soils were assigned to soils in the Hunfeld quadrangle area.

16. Compression wave velocity. Compression wave velocity was mapped for each of the three soil layers described in paragraph 14. Seismic velocity measurements collected in the Hunfeld area were used to differentiate between the various mapping classes.

17. Shear wave velocity. Ground truth seismic measurements were used to map shear wave velocities. The Poisson ratio was applied to calculate the shear wave class values for those sites where only compression wave velocities were measured. The Poisson ratio varied between 0.25 and 0.45 of the compression wave velocity depending upon the nature of the material. The data for the shear wave velocity of soil layer 1 are shown in Plate 3.

18. Water table depth. Only a limited amount of information on the stratigraphy of the Hunfeld quadrangle area was readily available. The large-scale geologic maps and lithologic descriptions of the area did not provide data on the depths and nature of the aquifers. Water well records from a few locations were helpful in defining the ground-water table in those specific areas. Other areas were mapped using surface phenomena such as rock outcrops, perennial marshes and areas with high surface moisture content, spring locations, and stream origins and patterns. The water table depth varies seasonally and annually; therefore, the water table depth factor was mapped to represent only the high-water table level.

19. Wet and dry soil strengths and land use. Wet soil strength, dry soil strength, and land use were obtained from data prepared for previous WES

studies (West, Krivitizky, and Randolph 1980; Dorion and West 1988) and were in digital format. Grid resolution is 30 m for the surface composition factors.

Vegetation factors

20. Vegetation factors were mapped using the 1:50,000-scale topographic map of Hunfeld, aerial photography (1:12,000 scale), and WES ground truth data obtained in 1978 (Hutto and West 1982). Mapped data were then digitized and gridded at a resolution of 30 m.

21. Vegetation types. The topographic map of Hunfeld, the base for determining vegetation types, identifies forested areas as deciduous, coniferous, and mixed. Photography and ground truth data aided in delineating orchards and agricultural areas; however, because crops are generally rotated annually, individual crop types could not be mapped. Vegetation type data for the Hunfeld quadrangle area are shown in Plate 4.

22. Vegetation heights. Vegetation heights for the croplands were not mapped because of the differing heights of various crops, the length of the growing season, and the inability to identify crop types within the agriculture area; therefore, vegetation heights for all the croplands were mapped as 0.5 to 2.0 m. Vegetation heights in the pastures and meadows ranged from 0.1 to 0.5 m and were mapped in this class.

23. Some ground truth data available for the Hunfeld area and an abundance of ground truth data for the Lauterbach quadrangle immediately west of the Hunfeld quadrangle served as the basis for determining tree heights. Heights of fruit trees (mostly apple) were established using existing data from various locations in Germany. A graphical display of the vegetation heights within the Hunfeld quadrangle is shown in Plate 5.

24. Vegetation canopy closures. Both maximum and minimum vegetation canopy closures were mapped. The percent canopy closure varies according to the vegetation growth cycle. The maximum canopy closure occurs at the peak of the growing season; the minimum canopy closure generally occurs during the winter period (December-April). Canopy closure for the agriculture areas was mapped as either zero for fallow land or 100 percent for mature crops. The remaining land cover types are forest, orchards, and urban areas. Because coniferous trees in this area do not lose their foliage, their percent canopy closure remains fairly constant throughout the year. Closure in the deciduous forests varies from less than 25 percent during the winter months to greater than 75 percent during the growing season. In the mixed forests, closure

varies depending on the season and the predominate types of trees. Orchards composed primarily of widely spaced deciduous trees have a canopy closure normally less than that of deciduous forests during the growing season. Plots of the minimum and maximum canopy closure data are displayed in Plates 6 and 7.

25. Vegetation density. The vegetation density was mapped as the stem count/900 sq m or an area 30 by 30 m based on the grid resolution. All agricultural areas fell within a single map unit (i.e., greater than 500 stems/30-m grid cell). Very little stem-spacing data were available for the Hunfeld area; however, data for the Lauterbach quadrangle, which were considered applicable, were used for mapping vegetation density. A limited number of sample sites within the study area and some aerial photography were employed to map vegetation density.

Climate/weather factors

26. The US Army Engineer Cold Regions Research and Engineering Laboratory prepared map data for maximum snow depth and average annual snowfall. These data were provided to WES and then were digitized and gridded at 30 m. The average annual snowfall map for the Hunfeld quadrangle area is shown in Plate 8.

Cultural feature factors

27. Cultural factors identified in Appendix A contained 16 features: building heights, building surface area, building density, building surface material, use, roof slopes, roof material types, roof temperature, road widths road surface materials, embankment heights, embankment slopes, subsurface material types, curvature, surface roughness, and temperature. Data for only four of these cultural features were readily available for inclusion in the prototype data set.

8. Urban areas, structure heights, and structure densities. Data for urban areas (cities, towns, and villages) and for structure heights and densities had already been compiled in digital format from the WES study by Doiron and West (1988). The digital data were resampled to 30-m grid resolution using Earth Resources Laboratory Application Software (National Aeronautics and Space Administration 1986).

29. Roads. The 1:50,000-scale Hunfeld topographic quadrangle served as the base map for generating road data. Three types of paved roads--autobahn (four-lane with median), primary, and secondary--were mapped. Unpaved trails were not included. Overlays for the three types of roads were prepared,

digitized, and then gridded at a resolution of 10 m. The road data within the Hunfeld quadrangle area are shown in Plate 9.

Hydrologic feature factors

30. Stream bank angle, height, gap width, stream bottom material, and bank vegetation density. Data on the hydrologic factors, namely stream bank angle, stream bank height, stream gap width, stream bottom material, and stream bank vegetation density, were obtained from map overlays prepared for an earlier WES study by Koeppel et al. (1979). Data were digitized from these overlays and gridded at a 10-m resolution. Data for the stream gap widths are shown in Plate 10.

31. Water velocity, width, and depth. The hydrologic feature data consisted of water velocity, water width, and water depth by the month. Information was formulated based on actual measured field data and records available on streams in the Hunfeld area. Data were prepared as an overlay to the 1:50,000-scale quadrangle map, digitized and gridded at a 10-m resolution. A more detailed description of the procedures used in the collection of the field data is provided by Doiron and West (1988).

Site-Specific Data

32. High-resolution (2.5-m grids) terrain data bases for four subareas or sites in West Germany were from an earlier WES study. One of these, designated as Site 6, is located within the Hunfeld 1:50,000-scale quadrangle area. Road transect data on 23 sites were also available for the Hunfeld quadrangle. Site location maps for the small terrain data base site (Site 6) and the road transect data base sites are included in Hutto and West (1982).

Site-specific areal terrain factor data

33. The high-resolution digital terrain data base for Site 6 was for a small area 250 by 900 m (Hutto and West 1982). The 21 parameters given in Table 2 were mapped, digitized, and gridded at a resolution of 2.5 m. Documentation on data collection and mapping procedures for this high-resolution data are described by Hutto and West (1982). These factors are stored as individual ASCII files.

Site-specific, road and terrain transect data

34. Road transect data for 23 road sites within the Hunfeld quadrangle are also included in this data set. Parameters reflect terrain and surface

features along both sides of the road from the center line out to a distance of approximately 100 to 125 m. Factors included are given in Table 3. Factor data for the road transect data base are presented for 2.5-m grid spacing starting at one end of the transect and proceeding continuously to the other end, a distance of 250 m.

Locations of nearest weather stations

35. Climatologic data were available from several weather stations in West Germany, including Fulda, which is the station closest to the Hunfeld. Table 4 lists the weather stations surrounding the Hunfeld area, their station identification numbers, geographic coordinates, and topographic elevations.

Site-specific
historic weather data

36. Historic weather data were compiled by the US Army Engineer Topographic Laboratory and stored in the Battlefield Environmental Effects (BEES) Data Base. Information is compiled by month for a number of climatologic factors for specific weather stations. Format for the BEES data is shown in Figure 4,* which depicts the climatic data for the Fulda, West Germany, weather station.

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

PART III: PRESENTATION OF DATA SET AND STORAGE FORMATS

Presentation of Data Set

37. The data base compilation procedures used for this study were developed over several years in support of various RDT&E studies. Table 5 offers a detailed listing of the factors presently included in the ESMDG prototype data set. In addition, the table provides information on grid resolution and the manner in which data are represented (classed or actual values).

38. Some of the data were displayed graphically as shown in Figure 3 and Plates 2-10 to illustrate factor variability and extent. The approximate scale for these figures is 1:155,000; however, factor maps can be displayed at any scale depending upon the type of plotter system and software. In addition to the maps, histograms have been generated to indicate the percentage of the total area covered by each selected factor mapping class (Figures 5-13). These histograms show relative distribution of each selected factor class within the Hunfeld area.

Storage Formats

39. The format of the areal terrain factors is a grid (raster) array with 30-m resolution. As the illustration of the layout shows (Figure 2), the point of reference (origin) is the upper left corner. Linear features occurring within the Hunfeld area are portrayed as grid arrays with a resolution of 10 m. Each of the 10- and 30-m digital terrain data factors covers the area of a 1:50,000-scale quadrangle map sheet.

40. Areal and linear factors in the prototype data set are individual binary files. Grid cell 1,1 (point of origin) is located at the northwest corner (Figure 2). Data files are stored in FORTRAN integer *4 binary format with a logical record length being the number of columns times four. Data were processed on a Vax 11-750 computer.

41. The original storage format of the terrain parameters (Table 2) and the road transect parameters (Table 3) in the high-resolution (2.5 m) digital terrain data base are described by Hutto and West (1982). The 21 terrain parameters are also stored as individual ASCII files. The elevation profiles

in the road transect data have been extracted from the original data and are now stored as ASCII files.

42. Climatologic data and the historic weather data are statistical data. Format for the BEES historical weather data is shown in Figure 4.

PART IV: CONCLUSIONS AND RECOMMENDATION

Conclusions

43. This digital environmental and terrain data set has been developed for the Hunfeld quadrangle, West Germany. Availability of information was a limiting factor in compiling the data set; however, those factors included cover a number of elements that affect the design, testing, evaluation, and operation of US Army materiel. The data set provides materiel designers with realistic terrain and environmental conditions in digital form for use with simulation performance prediction models.

44. Any problems resulting from limited factor data contained in the prototype will be corrected in the future as additional data are developed and included in the data set.

Recommendation

45. After US Army materiel developers have evaluated the adequacy of this prototype data set for supporting design, testing, and evaluation of materiel and after their recommendations are incorporated, additional data sets should be developed for other geographic areas for which materiel will be designed and fielded for operational use.

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Table 1

Data Base Factors

Topographic Factors

Elevation, m (actual values)
Slope, deg (actual values)
Slope aspect, deg (classed data)
Surface roughness (RMS x 10)
Obstacle type (random and linear)
Obstacle spacing, ft
Obstacle length, ft
Obstacle base width, in.
Obstacle vertical magnitude, in.
Obstacle approach angle, deg

Surface Composition Factors

USCS* soil types
Soil layer depth, 3 layers, cm
Soil permeability, cm
Soil compression wave, 3 layers, m/sec
Soil shear wave velocity, 3 layers, m/sec
Depth to water table, cm
Soil strength, wet, rating cone index (RCI)
Soil strength, dry, RCI
Land use

Vegetation Factors

Type
Height, m
Maximum canopy closure, percent
Minimum canopy closure, percent
Density, stems/900 sq m

Climate Weather Factors

Maximum snow depth, cm
Average annual snowfall, cm

Cultural Feature Factors

Structures
Urban areas, city, town, Village
Structure heights, m
Density, percent of grid covered

Roads
Road types

Hydrologic feature factors
Bank angle, deg
Bank heights, m
Stream gap width, m
Stream bottom material
Stream bank vegetation density, no. of stems/100 sq m
Water velocity, mps; water depth, cm; and water width, m by month

* Unified Soil Classification System.

Table 2

Terrain High Resolution Data Base

Vegetation type, dimensionless
Vegetation density, number of trees/unit area
Vegetation height, m
Vegetation crown branching height, m
Vegetation crown diameter, m
Vegetation stem diameter, cm
Surface soil strength or cone index, dimensionless
3-in.-depth soil strength or cone index, dimensionless
6-in.-depth soil strength or cone index, dimensionless
Soil or road type, dimensionless
Soil wet density, g/cc
Soil moisture content, percent
Subsurface soil layer 1 compression wave velocity, m/sec
Subsurface soil layer 1 depth, cm
Subsurface soil layer 2 compression wave velocity, m/sec
Subsurface soil layer 2 depth, cm
Subsurface soil layer 3 compression wave velocity, m/sec
Subsurface soil layer 3 depth, cm
Surface topographic elevation, cm
Absolute surface slope, deg from zenith
Surface slope aspect, deg clockwise from north

Table 3

Road Transect Data Base Parameters

Surface elevation as referenced to elevation of center line of road, cm

Surface slope, deg from zenith

Average stem diameter of trees, cm

Average height of trees, m

Average crown branching height of trees, cm

Average crown diameter of trees, cm

Types of trees (coded)
- 0 - no vegetation
- 1 - conifer
- 2 - deciduous
- 3 - mixed
- 4 - grassland

Area of vegetation sample cell selected for measurement of individual tree characteristics, m

Number of individual trees measured in sample cell

Types of surface material (coded)
- 1 - Surface rock
- 2 - Clean gravel (GW/GP)
- 3 - Gravels with fines (GM/GS)
- 4 - Sands with fines (SM/SC)
- 5 - Silts and clays, medium to low plasticity (ML/CL/OL)
- 6 - Silts and clays, medium to high plasticity (MH/OH/CH)
- 7 - Highly organic material (Pt)
- 8 - Limestone or basalt material
- 9 - Asphalt or concrete surface

Moisture content of soil, percent

Wet density of soil, g/cc

Table 4

Locations and Elevations of Weather Stations, Hunfeld Area, West Germany

Station ID No.	City	Lat. N Deg	Lat. N Min	Long. E Deg	Long. E Min	Elevation m
107550	Ansbach	49	18	10	35	413
106265	Bad Kreuznach	49	51	7	53	105
109710	Bad Tolz	47	46	11	36	716
106190	Baumholder	49	38	7	18	426
106100	Bitburg	49	57	6	34	375
108690	Erding	48	19	11	57	460
107655	Feucht	49	23	11	10	386
106335	Finthen	49	58	8	09	231
106370	Frankfurt/Rhein/Main	50	03	8	35	112
105445	Fulda*	50	33	9	39	305
106870	Grafenwohr	49	42	11	57	414
106160	Hahn	49	57	7	15	503
106420	Hanau	50	10	8	57	112
107340	Heidelberg	49	24	8	39	110
107715	Hohenfels	49	13	11	50	442
107520	Illesheim/Nurnberg	49	28	10	23	325
106590	Kitzingen	49	45	10	12	210
106140	Ramstein	49	26	7	35	237
107450	Schwaebisch Hall	49	07	9	47	398
107120	Sembach AB	49	31	7	52	321
108605	Siegenberg	48	45	11	48	404
106070	Spangdahlem	49	58	6	42	365
107370	Stuttgart	48	46	9	11	305
106570	Wertheim	49	46	9	29	338
106330	Wiesbaden	50	03	8	20	140
107140	Zweibrucken	49	13	7	25	343

* Closest station to Hunfeld.

Table 5

Factor Classes Included in the ESMDG Prototype Data Set

Factor	Resolution, m
Slope, deg actual values	30
Slope aspect, deg	30
Class — Direction (Range, deg) 1 — No aspect 2 — N, 338-22 3 — NE, 23-67 4 — E, 68-112 5 — SE, 113-157 6 — S, 158-202 7 — SW, 203-247 8 — W, 248-292 9 — NW, 293-337 10 — No data	
Elevation, m actual values	30
Surface roughness (RMS × 10) actual values	30
Obstacle type	30
Class — Type 1 — random 2 — linear	
Obstacle spacing, ft actual values	30
Obstacle length, ft actual values	30
Obstacle base width, in. actual values	30
Obstacle vertical magnitude, in. actual values	30
Obstacle approach angle, deg actual values	30

(Continued)

Table 5 (Continued)

Factor		Resolution, m
Soil type		30
Class	USCS Classification	
1	No data	
2	GW	
3	GP	
4	GM	
5	GC	
6	SW	
7	SP	
8	SM	
9	SC	
10	ML	
11	CL	
12	OL	
13	MH	
14	CH	
15	OH	
16	Pt	
17	Rock	
18	PS	
19	EV	
20	No soil	
Soil permeability		30
Class	Range, cm	
1	No soil	
2	<0.15	
3	0.15-0.50	
4	0.51-1.50	
5	1.51-5.00	
6	5.01-15.00	
7	15.01-50.00	
8	>50.00	
Soil layer depth (3 layers)		30
Class	Range, cm	
1	No layer	
2	0-20	
3	21-120	
4	121-200	
5	201-300	
6	301-500	
7	501-700	
8	701-900	
9	>901	
10	Urban areas	

(Continued)

Table 5 (Continued)

Factor		Resolution, m
Compression wave velocity (3 layers)		30
Class	Range, m/sec	
1	No layer	
2	0-300	
3	301-450	
4	451-600	
5	601-750	
6	751-900	
7	901-1,400	
8	1,401-1,900	
9	>1,900	
10	Urban areas	
Soil shear wave velocity (3 layers)		30
Class	Range, m/sec	
1	No layer	
2	0-75	
3	76-120	
4	121-150	
5	151-180	
6	181-240	
7	241-300	
8	301-360	
9	361-450	
10	451-560	
11	561-760	
12	>760	
13	Urban areas	
Water table depth		30
Class	Range, cm	
1	No data	
2	0 (Surface)	
3	>0-30	
4	>30-100	
5	>100-200	
6	>200-300	
7	>300-400	
8	>400-700	
9	>700-1,000	
10	>1,000	
11	No water	
Soil strength, wet		
RCI		30

(Continued)

Table 5 (Continued)

Factor	Resolution, m
Soil strength, dry RCI	30
Land use	30

Land Use Codes

X	Y	Z
1 Urban	1 Village	0 Clear
	2 Town	1 With trees, shrubs
	3 City	2 Swampy
		3 W/drainage ditches
2 State forest	1 Deciduous	4 W/dry ditches
	2 Coniferous	5 W/walls
	3 Mixed	6 W/hedges
	4 Deciduous swamp	7 W/banks
	5 Coniferous swamp	8 W/banks, hedges
	6 Mixed swamp	9 Controlled planting reforested
3 Nonstate forest	1 Deciduous	
	2 Coniferous	
	3 Mixed	
	4 Deciduous swamp	
	5 Coniferous swamp	
	6 Mixed swamp	
4 Meadows/pastures	0 Clear	
	1 W/trees	
	2 Swampy	
5 Croplands	0 Clear	
	1 W/trees	
	2 Swampy	
6 Other agriculture	1 Nursery	
	2 Orchard	
	3 Vineyard	
	4 Hop garden	
7 Other	1 Swamp, bog	
	2 Peat cutting	
	3 Undetermined	
	4 Reed area	
	5 Heath, bent	
	6 Undermined	
	7 Rock	
	8 Sand	
	9 Quarry, pit	
8 Out of Bounds		

(Continued)

Table 5 (Continued)

Factor			Resolution, m
	Land Use Codes (Continued)		
X	Y	Z	
9 Miscellaneous	0 River 1 Lake 2 Lake clusters		

Vegetation type — 30

Class	Description
1	No vegetation
2	Deciduous forest
3	Coniferous forest
4	Mixed forest
5	Meadow/pasture
6	Croplands
7	Other agriculture
8	Marsh vegetation
9	No data

Vegetation height — 30

Class	Range, m
1	No vegetation
2	0.1-0.5
3	>0.5-2.0
4	>2.0-5.0
5	>5.0-12.0
6	>12.0-18.0
7	>18.0-24.0
8	>24.0-30.0
9	>30.0

Vegetation density — 30

Class	Range/900 sq m
1	No data
2	<20
3	20-40
4	<40-80
5	>80-120
6	>120-200
7	>200-500
8	>500
9	Croplands/pastures
10	No vegetation

(Continued)

Table 5 (Continued)

Factor		Resolution, m
Maximum canopy closure		30
Class	Range, Percent Closure	
1	No data	
2	<25	
3	25-50	
4	50-75	
5	>75	
6	Nonforested	
Minimum canopy closure		30
Class	Range, Percent Closure	
1	No data	
2	<25	
3	25-50	
4	>50-75	
5	>75	
6	Nonforested	
Maximum snow depth		30
Class	Snow Depth Range, cm	
1	No snow	
2	<35	
3	35-45	
4	>45-60	
5	>60-70	
6	No data	
Average annual snowfall		30
Class	Average Snowfall Range, cm	
1	No snow	
2	<50	
3	50-90	
4	>90-110	
5	No data	
Urban areas		30
Class		
1	Nonurban	
2	Village	
3	Town	
4	City	

(Continued)

Table 5 (Continued)

Factor	Resolution, m
Structure height	30
Class / Height Range, m	
1 — No buildings	
2 — <5	
3 — 5-10	
4 — >10-20	
5 — >20-30	
6 — >30-50	
7 — >50	
Structure density, percent	30
Road types	10
Class / Type	
1 — No roads	
2 — Autobahn (four-lane with median)	
3 — Primary roads (6-10 m wide)	
4 — Secondary roads (4-6 m wide)	
R/L Stream bank angle (deg)	10
Class / Slope Range, Deg	
1 — No gap	
2 — 0-10	
3 — >10-20	
4 — >20-45	
5 — >45-75	
6 — >75	
7 — No data	
Stream gap width	10
Class / Gap Width Range, m	
1 — No gap	
2 — 0-3	
3 — > 3-6	
4 — > 6-9	
5 — > 9-12	
6 — >12-15	
7 — >15-18	
8 — >18-21	
9 — >21-24	
10 — >24	
11 — No data	

(Continued)

Table 5 (Continued)

Factor													Resolution, m
Average stream width (W), m; depth (D), cm, by month; and velocity (V), mps													10
Class No.		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	No stream												
2	W	9	9	9	9	0	0	0	0	0	0	0	0
	D	100	100	100	100	0	0	0	0	0	0	0	0
	V	1	1	1	1	0	0	0	0	0	0	0	0
3	W	3	3	3	3	3	3	3	3	3	3	3	3
	D	100	100	100	100	100	100	100	100	100	100	100	100
	V	1	1	1	1	1	1	1	1	1	1	1	1
4	W	6	6	6	6	6	6	6	6	6	6	6	6
	D	100	100	100	100	100	100	100	100	100	100	100	100
	V	1	1	1	1	1	1	1	1	1	1	1	1
5	W	9	9	9	9	9	9	9	6	6	6	9	9
	D	100	100	100	100	100	100	100	100	100	100	100	100
	V	1	1	1	1	1	1	1	1	1	1	1	1
6	W	9	9	9	9	9	9	9	9	9	9	9	9
	D	100	100	100	100	100	100	100	100	100	100	100	100
	V	1	1	1	1	1	1	1	1	1	1	1	1
7	W	12	12	12	12	12	12	12	12	12	12	12	12
	D	100	100	100	100	100	100	100	100	100	100	100	100
	V	1	1	1	1	1	1	1	1	1	1	1	1
8	W	12	12	12	12	12	12	12	12	12	12	12	12
	D	200	200	200	200	200	200	200	200	200	200	200	200
	V	1	1	1	1	1	1	1	1	1	1	1	1
9	W	15	15	15	15	12	12	12	12	12	12	15	15
	D	100	100	100	100	100	100	100	100	100	100	100	100
	V	1	1	1	1	1	1	1	1	1	1	1	1
10	W	15	15	15	15	15	15	15	15	15	15	15	15
	D	500	500	500	500	500	500	500	500	500	500	500	500
	V	1	1	1	1	1	1	1	1	1	1	1	1
11	No data												

(Continued)

Table 5 (Concluded)

Factor	Resolution, m
Stream bank height	10

Class	Height Range, m
1	No stream
2	0-0.5
3	>0.5-1.0
4	>1.0-2.0
5	>2.0-3.0
6	>3.0-5.0
7	>5.0
8	No data

Stream bottom material	10

Class	USCS Classification
1	No stream
2	GW, GM, GC
3	ML, CL
4	CH
5	ROCK
6	No data

Stream bank vegetation density			10
	Stem Diameters Range, cm		
No. of Stems/100 sq m	5-25	>25-50	>50
None	1	1	1
1-5	2	2	2
>5-10	3	3	3
>10	4	4	4

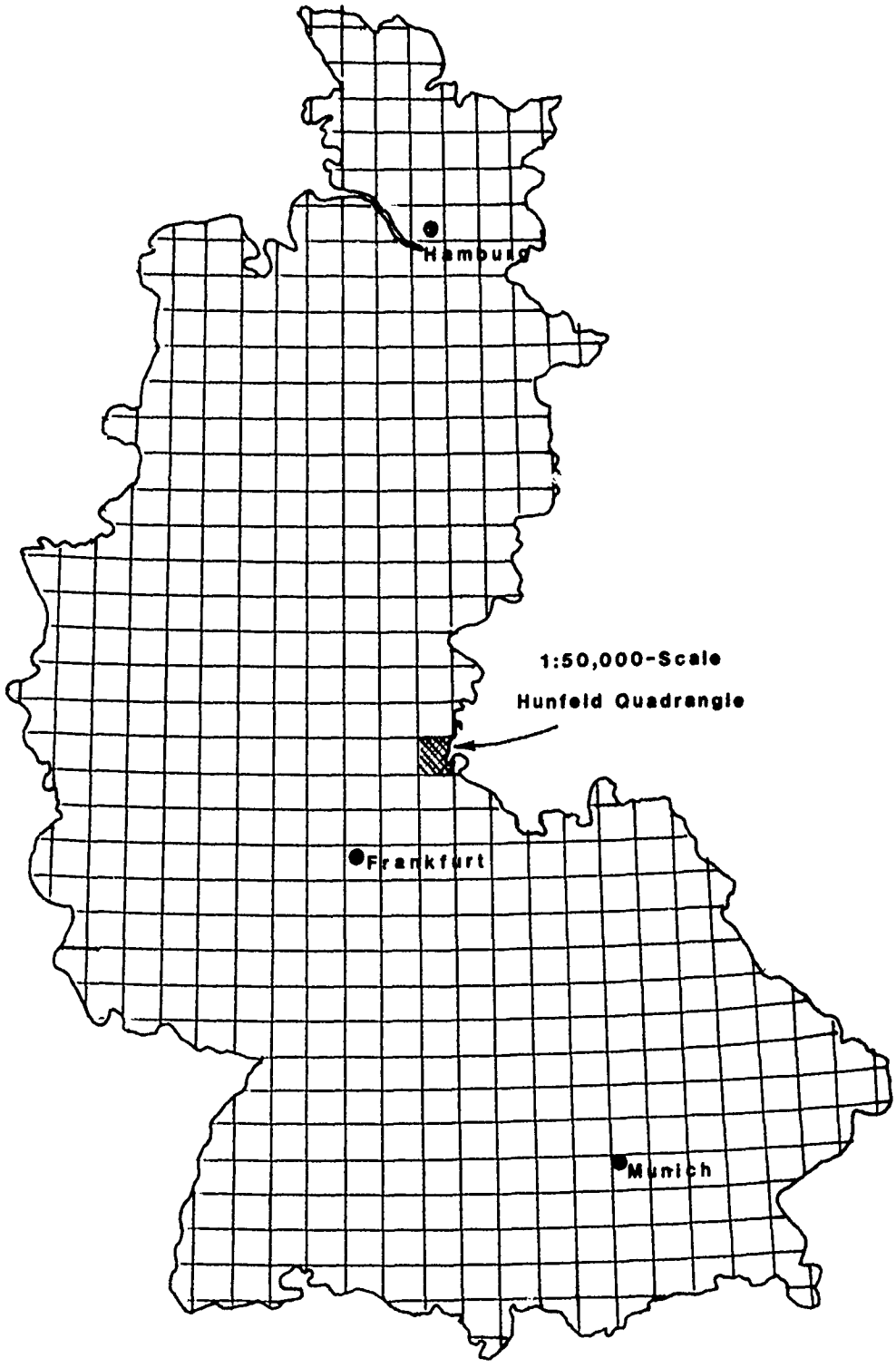

Figure 1. Location of the prototype environmental data set (Hunfeld quadrangle) in the Federal Republic of Germany

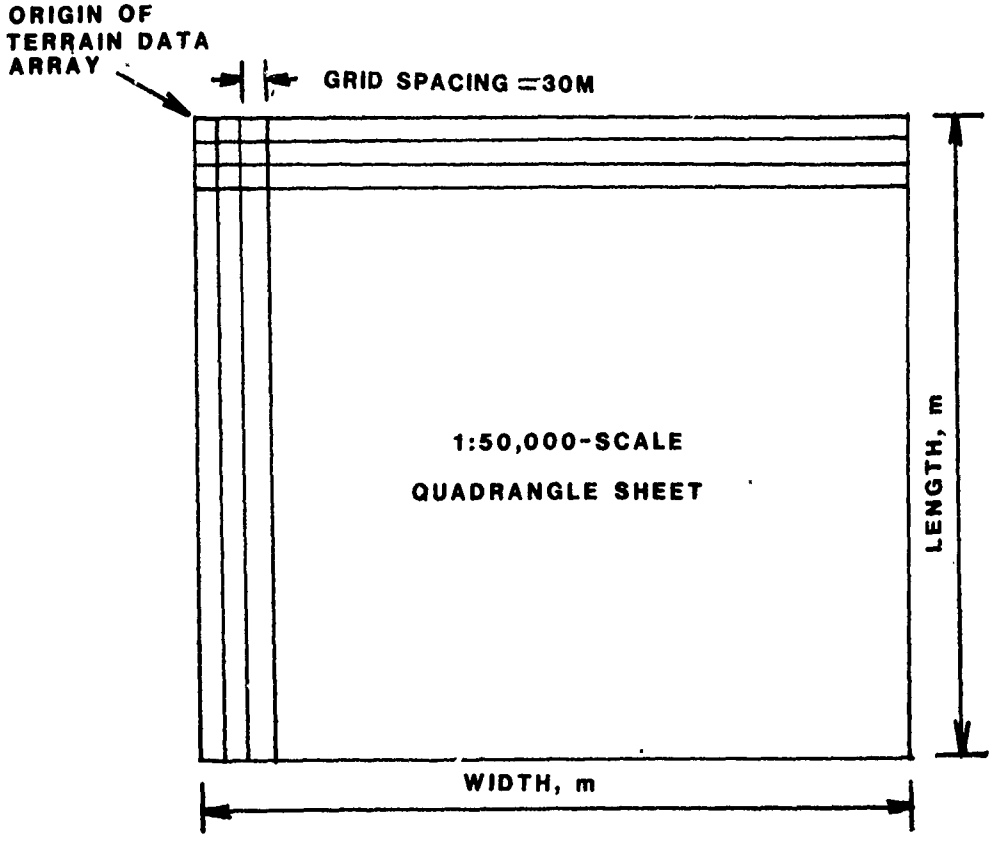

Figure 2. Layout for the gridded terrain data arrays for the ESMDG prototype data set

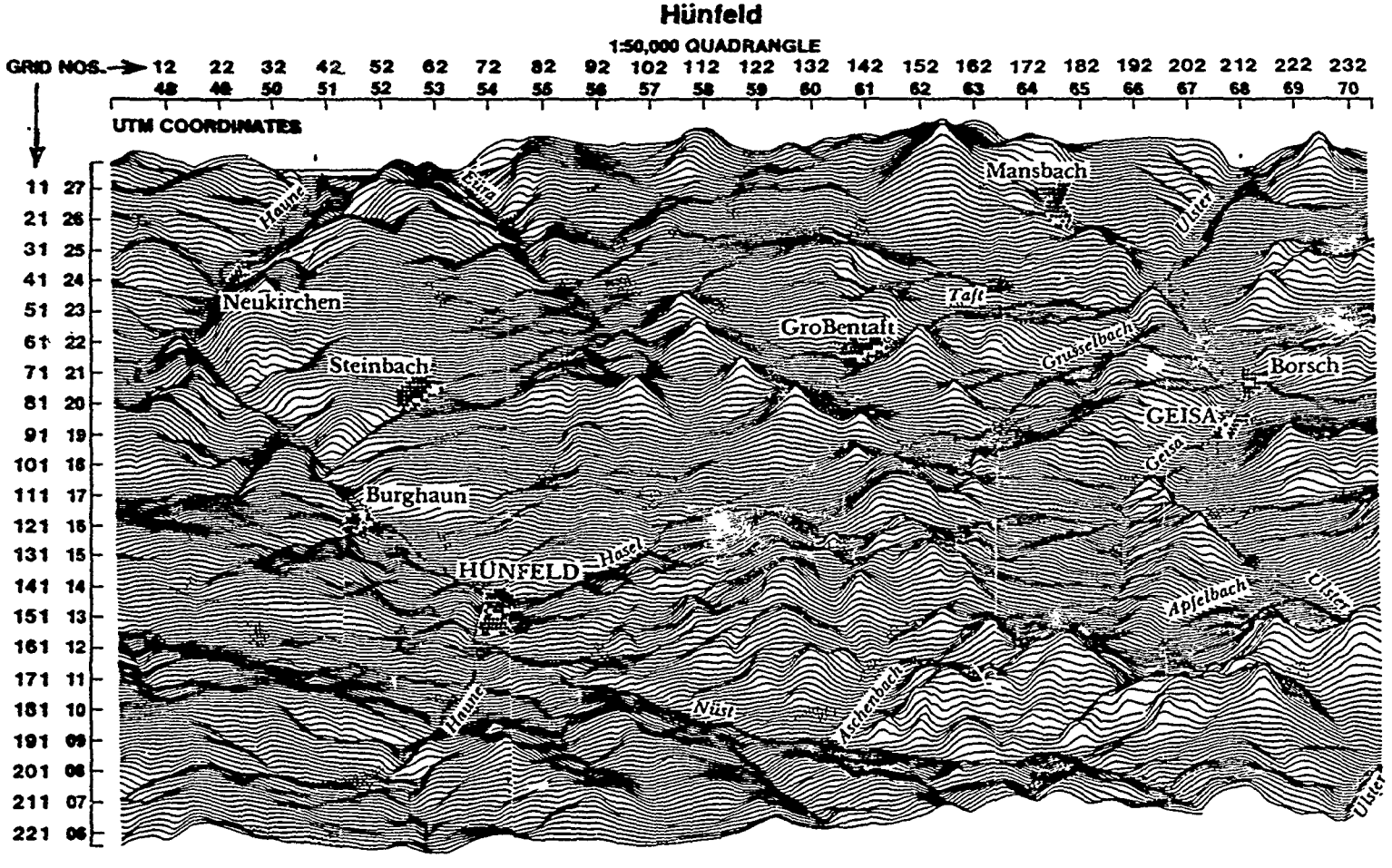

Figure 3. Computer-drawn plot of the terrain surface within the Hunfeld quadrangle. Plot constructed using 100-m gridded elevation data. Cities and rivers were hand placed on the map for reference

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**********************************************************************
*                    --A BEES CLIMATOLOGY PRODUCT                    *
*                                                                    *
*  The following climatic data were extracted from up to fourteen    *
*  of the best available climatic data sources                       *
*                                                                    *
*                          * * CAUTION * *                           *
*  1)  Data in categories with short periods of record (years)       *
*      may not be representative of actual average conditions!       *
*  2)  'M' indicates missing data!                                   *
*                                                                    *
**********************************************************************
```

CLIMATIC INFORMATION FOR: FULDA, WESTGERMANY

STATION NUMBER . 35053

LATITUDE .50deg32'N LONGITUDE...09deg38'E
ELEVATION (in feet) ..1018
LOCATIONAL DESCRIPTOR. INTERIOR UPLAND

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEARS	CRIG
ABSOLUTE MAX TEMPERATURE(deg F)	54.	60.	74.	86.	84.	88.	92.	94.	89.	80.	66	58	10.	10.
MEAN DAILY MAX TEMPERATURE(deg F)	37.	38.	48.	53.	64.	68	72.	70	64.	58	48.	38	4.	10.
MEAN DAILY MIN TEMPERATURE(deg F)	31.	28.	36.	36.	45.	50.	53.	50	47.	41	31.	31.	4.	10.
ABSOLUTE MIN TEMPERATURE(deg F)	-9.	-5.	1.	23.	29.	31.	37.	37	29.	23.	11.	-7.	10.	10.
MEAN MONTHLY TEMPERATURE(deg F)	34.	33.	42.	45.	55.	59.	63.	60	56.	50.	36.	35	4.	10.
MEAN MONTHLY DEWPOINT(deg F)	27.	28.	31.	38.	44.	51.	53.	53	50.	45	35.	28.	10.	2
REL HUMIDITY AT 0400 LOCAL TIME	90.	88.	87.	80.	89.	92.	92.	94	94.	94.	91.	89.	10.	10.
REL HUMIDITY AT 1300 LOCAL TIME	84.	79.	71.	63.	59	58	58	61.	66.	75.	83.	85.	10.	10.
MEAN # OF DAYS w/MAX TEMP) 90 F	0.	0.	0.	0.	0.	0.	(.5	(.5	0	0.	0.	0	10.	10.
MEAN # OF DAYS w/MAX TEMP (32 F	9.	4.	1.	(.5	0	0	0	0	0	(.5	2.	7	42.	4.
MEAN # OF DAYS w/MIN TEMP (32 F	28.	17.	12.	6.	1.	(.5	0.	0.	1.	7.	18.	18	4.	10.
MEAN # OF DAYS w/MIN TEMP (0 F	1.	(.5	0.	0.	0.	0.	0.	0.	0.	0.	0.	(.5	10.	10.
MEAN MONTHLY PRECIPITATION(in)	1.3	2.5	2.2	2.5	2.6	3.3	3.4	2.9	1.6	1.3	2.6	4.7	6.	10
MAX MONTHLY PRECIPITATION(in)	1.8	3.2	2.2	3.3	3.	4.4	5.7	4.8	2.4	2.6	3.7	5.4	7.	2.
MIN MONTHLY PRECIPITATION(in)	0.9	1.8	2.2	1.5	2.2	1.5	0.7	1.4	1.	0.4	1.5	4	7.	2.
MAX 24-hr PRECIPITATION(in)	0.6	1.2	0.6	1.2	0.8	2.3	1.2	1.5	1.1	0.8	1.1	1.4	6	10.
AVG # OF DAYS w/PRECIP) trace	16.	13.	14.	14.	14.	15	15	16	14.	15.	15.	18	48.	4.
AVG # OF DAYS w/PRECIP) 0.1 in	M	M	M	M	M	M	M	M	M	M	M	M	M	M
AVG # OF DAYS w/SNOWFALL) 1.5 in	2	1.	(.5	0	0	0	0	0	0	0	2	2	6.	10.
MAX DEPTH OF SNOWFALL ON GROUND(in)	14	19	7	2.	0.	0.	0	0	0.	0.	4.	8	M	4.
MAX MONTHLY SNOW/ICE PELLETS	16	6	2.	2.	0.	0.	0.	0	0.	0.	12.	8.	6.	2.
MAX 24-hr SNOW/ICE PELLETS	4.	6.	3.	1.	(.5	0.	0.	0	0.	0.	5.	4.	5.	10.
AVG # OF DAYS w/THUNDERSTORMS	1.	2	2.	(.5	4.	6	6.	6	2	(.5	2.	(.5	3.	10.
MEAN WINDSPEED(kts)/PREVAILING DIREC	6SSW	6SSW	7SW	6SW	6SW	SSW	SSW	SSW	SSSW	SSSW	6SSW	6SSW	10.	10.
PCT FREQ OF OBS w/SURFACE WIND) 17 kts	3.	2.4	2.	2.	1.	0.5	0.7	0 3	0 6	1.4	3.	3.	10.	2.
PEAK GUST (kts/direction)	36SW	50SSW	44W	44W	42WSW	38W	39W	60SW	32W	52SW	39W.	48W	5.	2.
AVG # OF DAYS w/BLOWING SAND OR DUST	M	M	M	M	M	M	M	M	M	M	M	M	M	M
PERCENT FREQ OCCUR OF FOG	36.	25.	18.	16.	11.	13.	14	19.	27.	31.	44	40.	11.	2.
PCT FREQ OBSNS w/VISIBILITY (5/8 mi	6.3	5.3	2.4	3.3	2.2	2.1	2.1	4.3	11.4	13.1	9.7	6.	11.	2.
PCT FREQ OBSNS w/VISIBILITY (2.5 mi	34.	28.	19.	11.	8.	7	8.	11.	21.	25.	28.	35.	11.	2.
MEAN CLOUDINESS IN PERCENT	90.	88.	78.	80.	78.	78	78.	78.	78.	78.	90	90.	10.	10.
PERCENT OF POSSIBLE SUNSHINE	M	M	M	M	M	M	M	M	M	M	M	M	M	M
PCT FREQ OF OBSNS w/CEILING HT (400 ft	4.	3.	1.	2.	1.	1.	1	3	7	10.	8	5	11.	2.
PCT FREQ OF OBSNS w/CEILING HT (1000ft	23.	15	9.	7.	4.	4	4	6	11	17	24.	26	11.	2.
PCT FREQ OF OBSNS w/CEILING HT (2000ft	43.	33	24.	18.	10.	10	9.	12.	18.	28.	41.	47.	11.	2.
PCT FREQ OF OBSNS w/CEILING HT (5000ft	68.	61	55.	48.	38.	34.	35.	35	39.	48.	66.	71.	11.	2.
STATION PRESSURE (mbs)	984.	982	983.	981.	983.	983	983.	986	984	985.	985	983.	M	13

Figure 4. Example of the Battlefield Environmental Effects (BEES) historic weather data, Fulda, West Germany, weather station

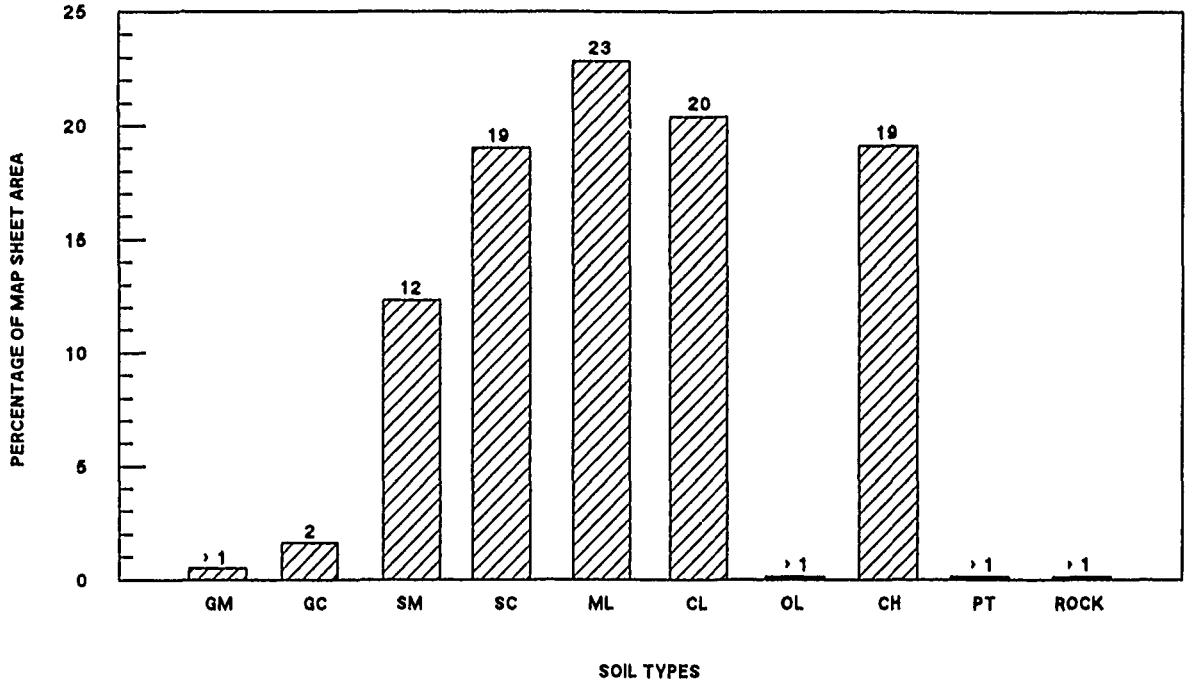


Figure 5. Histogram of soil types within the 1:50,000-scale Hunfeld quadrangle

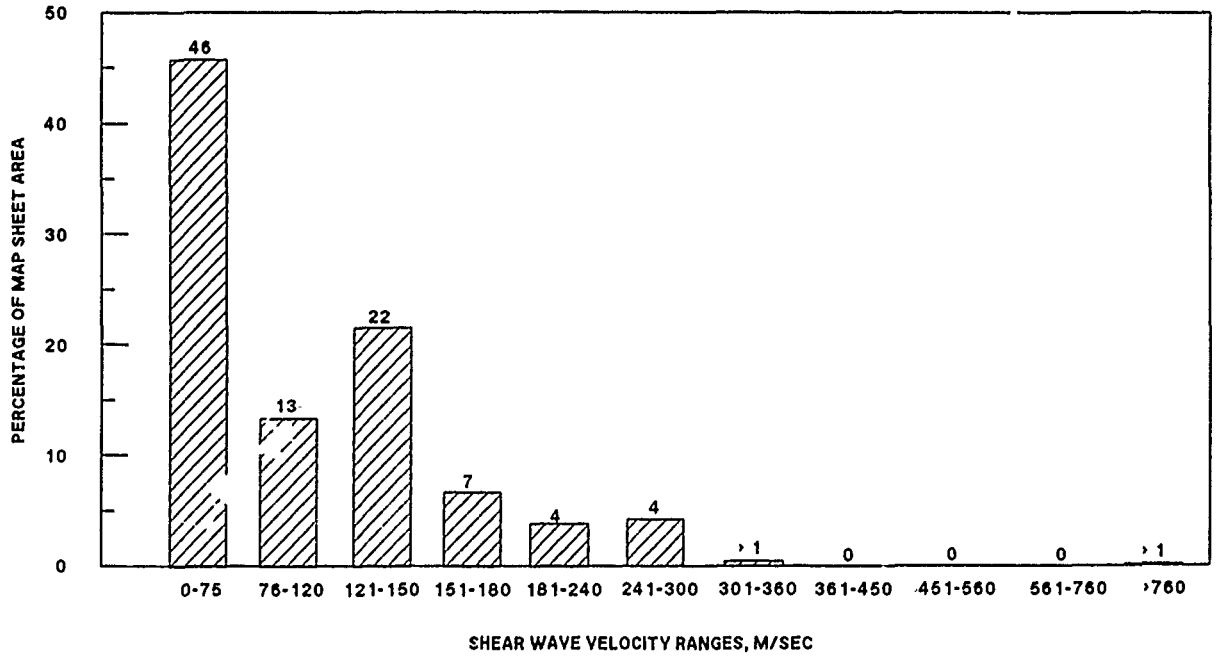


Figure 6. Histogram of shear wave velocities of soil layer 1 within the 1:50,000-scale Hunfeld quadrangle

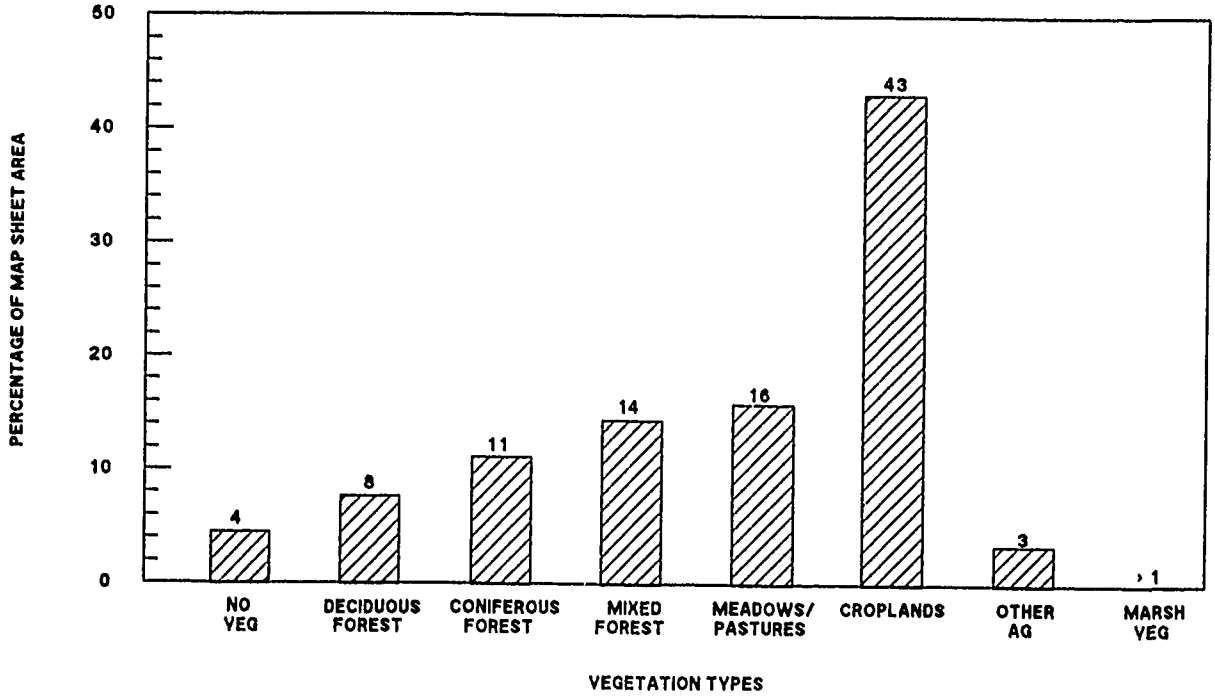


Figure 7. Histogram of vegetation types within the 1:50,000-scale Hunfeld quadrangle

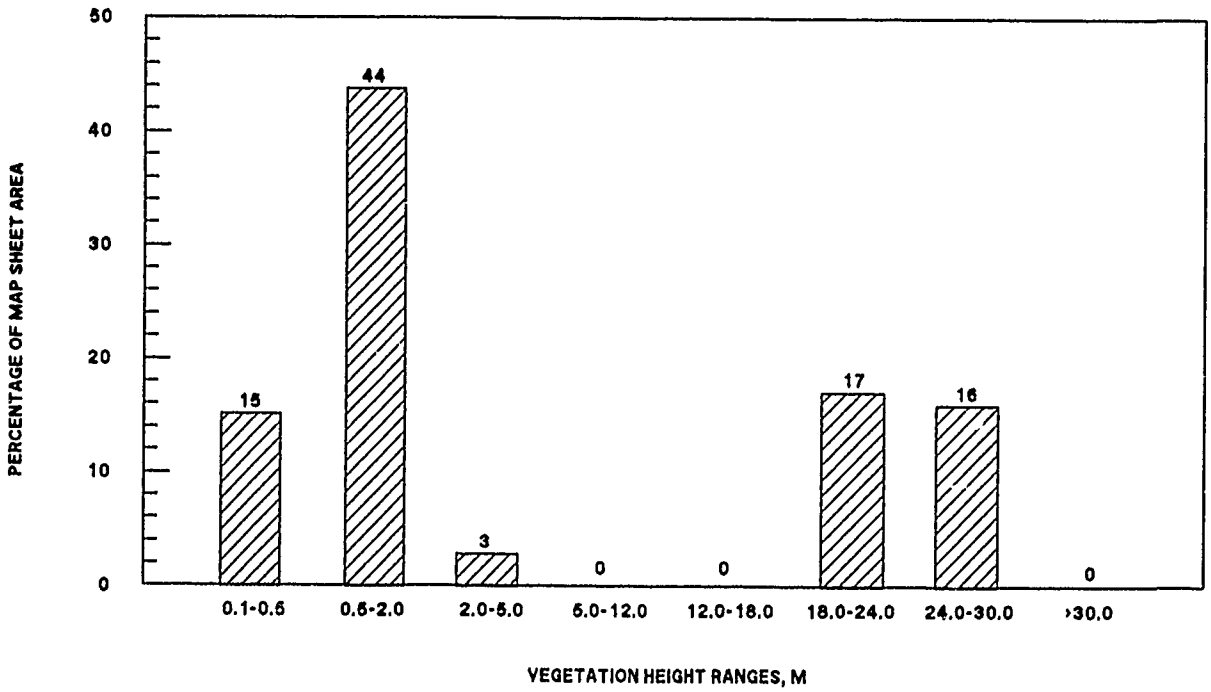


Figure 8. Histogram of vegetation heights within the 1:50,000-scale Hunfeld quadrangle

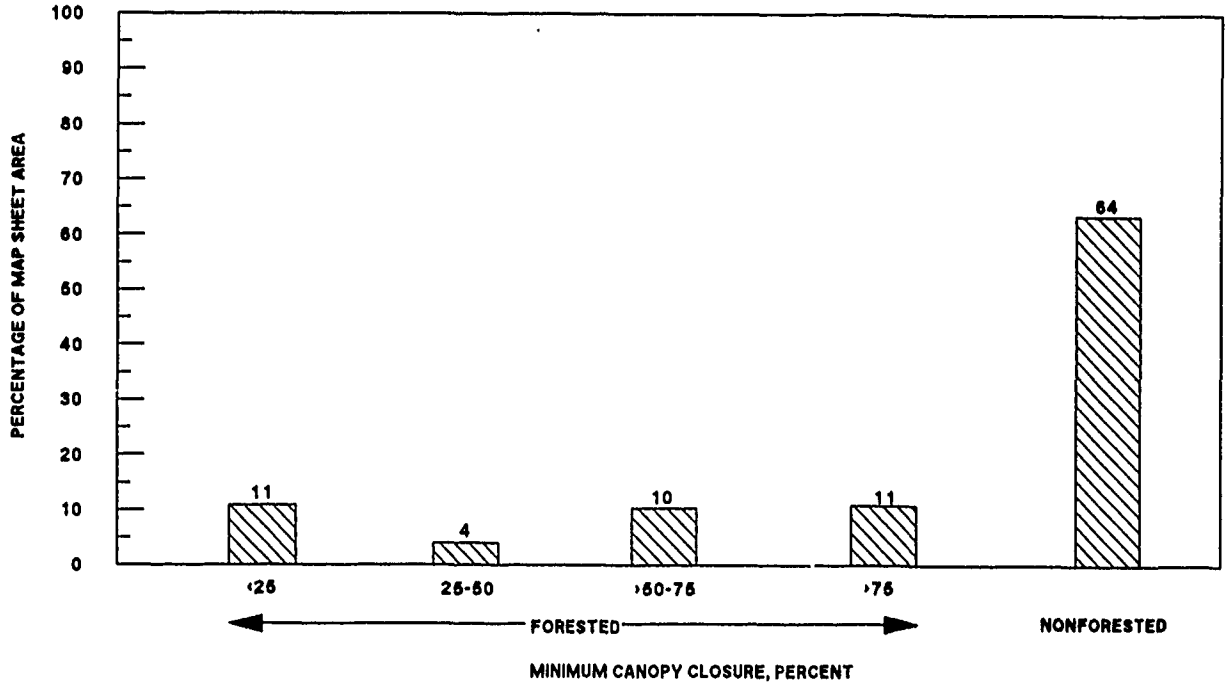


Figure 9. Histogram of minimum canopy closures within the 1:50,000-scale Hunfeld quadrangle

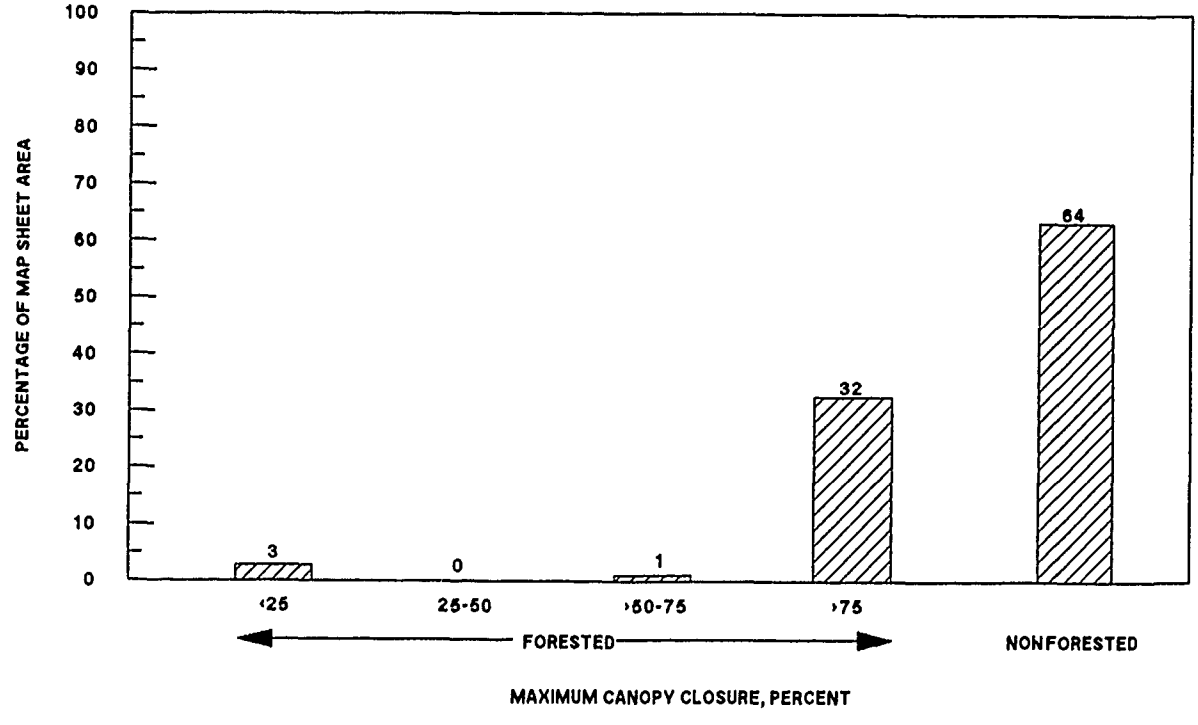


Figure 10. Histogram of maximum canopy closures within the 1:50,000-scale Hunfeld quadrangle

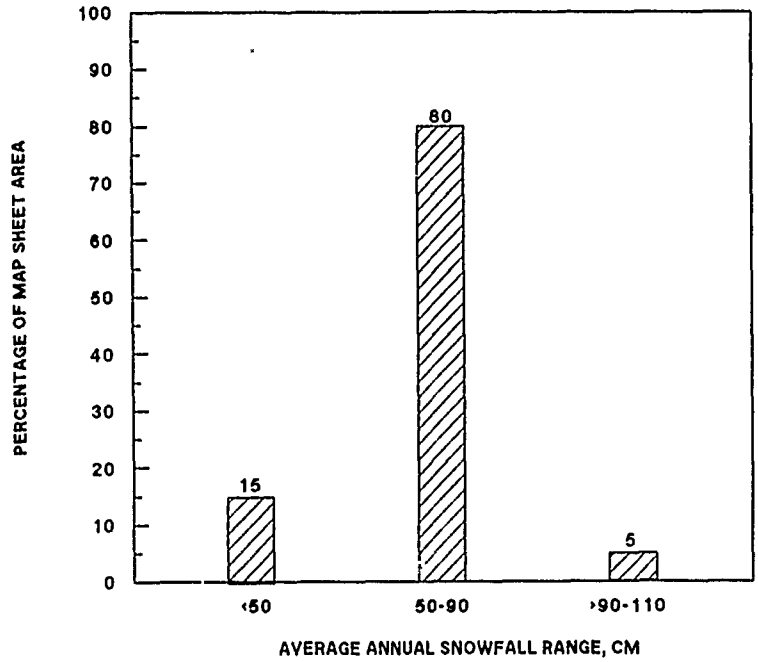


Figure 11. Histogram of average annual snowfall within the 1:50,000-scale Hunfeld quadrangle

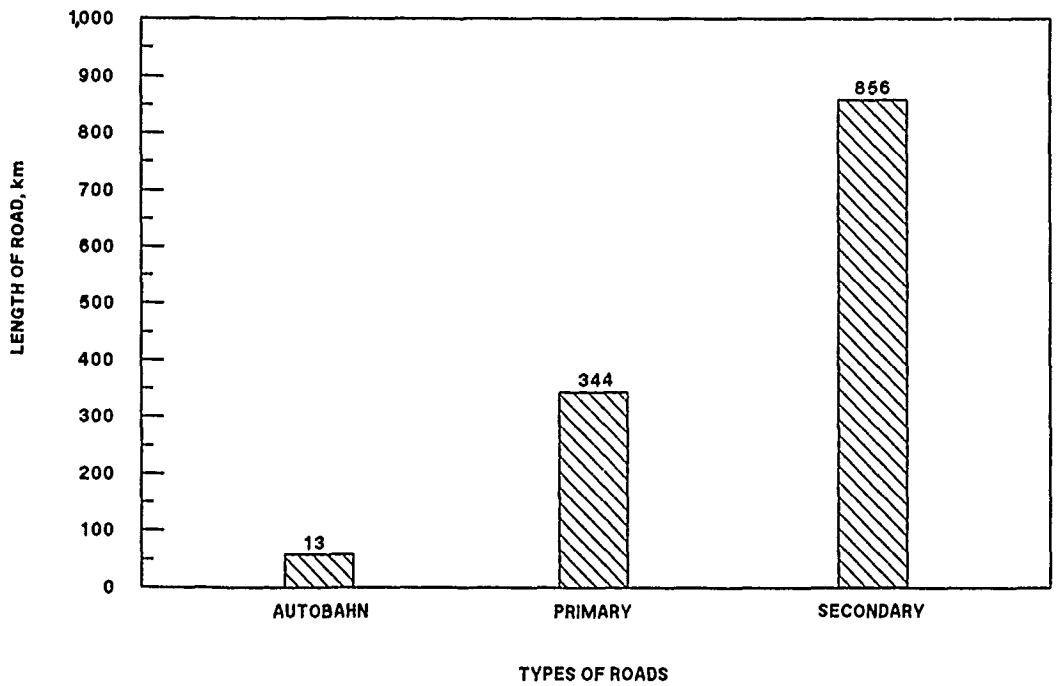


Figure 12. Histogram of road types within the 1:50,000-scale Hunfeld quadrangle

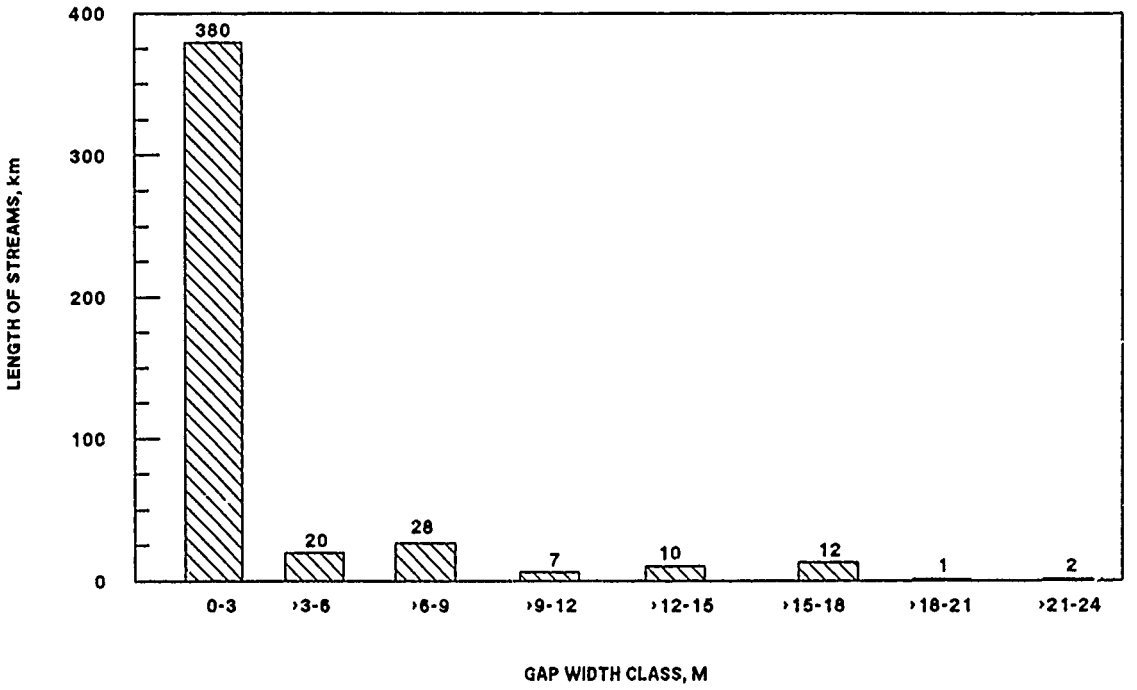


Figure 13. Histogram of stream gap widths within the 1:50,000-scale Hunfeld quadrangle

APPENDIX A: CRITICAL FACTORS IN THE DEVELOPMENT AND TESTING OF NINE CATEGORIES OF MATERIEL

The critical factors that are important to the development and testing of mine systems, vehicle systems, sensor systems, bridging systems, munitions, direct-fire weapon systems, top-attack weapon systems, communication systems, and air systems were determined. These factors are presented in Tables A1-A9.

Table A1

Mine Systems

Parameters	Conv*	Scatt*	Wam*
Topographic			
Slope magnitude			X
Slope aspect			X
Elevation		X	X
Microsurface roughness			X
Surface composition			
USCS Soil type		X	X
Soil strength		X	X
Soil moisture content		X	X
Soil density		X	X
Soil permeability			
Soil temperature			
Soil shear wave velocity			X
Soil compression wave velocity			X
Soil layer depth			
Depth to water table			
Soil reflectivity			X
Soil emissivity			
Soil specific heat			
Soil mineral content			
Snow depth	X	X	X
Snow density	X	X	X
Frozen layer depth			X
Snow hardness	X	X	X
Snow cover, percent	X	X	X
Snow crystal type			X
Snow temperature gradient			X
Snow roughness			X
Snow emissivity			X
Snow reflectivity			X
Vegetation			
Type	X	X	X
Height		X	X
Density/spacing	X	X	X
Canopy closure		X	X
Ground cover		X	X
Stem diameters		X	X
Foliage density		X	X
Branch density		X	X

(Continued)

* Conv = Conventional; Scatt = Scatterable; Wam = Wide area (SMART).
** USCS = Unified Soil Classification System.

Table A1 (Continued)

Parameters	Conv	Scatt	Wam
Reflectivity			X
Emissivity			X
Absorptivity			X
Hydrologic features			
Gap width	X	X	X
Gap depth	X	X	X
Water width		X	X
Bank slopes	X	X	X
Water velocity	X	X	X
Water depth	X	X	X
Water temperature	X	X	X
Bottom material (USCS soil types)	X	X	X
Sediment concentration	X	X	X
Stream bank vegetation density		X	X
Ice thickness	X	X	X
Ice type	X	X	X
Ice cover, percent	X	X	X
Ice strength		X	X
Cultural features			
Roads			
Width		X	X
Surface material type		X	X
Temperature			X
Embankment slope	X	X	X
Embankment height			X
Subgrade material type			X
Curvature		X	X
Surface roughness		X	X
Structures			
Height		X	X
Building surface area		X	X
Density		X	X
Material type			
Use			
Roof slope			
Roof material type			
Roof temperature			X
Climate/weather profile			
Air temperature			X
Wind velocity			X

(Continued)

Table A1 (Concluded)

Parameters	Conv	Scatt	Wam
Climate/weather profile (Cont'd)			
Wind direction			X
Solar radiation			X
Precipitation rates (rain, snow, hail)	X	X	X
Lightning rates			
Water vapor density (absolute humidity)			
Dew point (relative humidity)			
Cloud cover			
Barometer pressure			
Glazing			
Hoar frost			
Freeze-thaw cycles		X	X
Ozone level			
Freezing degree days			
Obscurants (natural and BIC*)			
Type			X
Size distribution			X
Refractive index			X
Density			X

* BIC = battlefield-induced contaminants.

Table A2

Vehicle Systems

Parameters	TRKD*	WHLD*	ROBOTIC
Topography			
Slope magnitude	X	X	X
Slope aspect	X	X	X
Elevation	X	X	X
Microsurface roughness	X	X	X
Surface composition			
USCS soil type	X	X	X
Soil strength	X	X	X
Soil moisture content	X	X	X
Soil density	X	X	X
Soil permeability	X	X	X
Soil temperature	X	X	X
Soil shear wave velocity			
Soil compression wave velocity			
Soil layer depth	X	X	X
Depth to water table	X	X	X
Soil reflectivity			X
Soil emissivity			X
Soil specific heat			X
Soil mineral content	X	X	X
Snow depth	X	X	X
Snow density	X	X	X
Frozen layer depth	X	X	X
Snow hardness	X	X	X
Snow cover, percent	X	X	X
Snow crystal type	X	X	X
Snow temperature gradient			
Snow roughness	X	X	X
Snow emissivity			X
Snow reflectivity			X
Vegetation			
Type	X	X	X
Height	X	X	X
Density/spacing	X	X	X
Canopy closure			
Ground cover	X	X	X
Stem diameters	X	X	X
Foliage density			
Branch density			

(Continued)

* TRKD = Tracked; WHLD = Wheeled.

Table A2 (Continued)

Parameters	TRKD	WHLD	ROBOTIC
Vegetation (Cont'd)			
Reflectivity			
Emissivity			
Absorptivity			
Hydrologic features			
Gap width	X	X	X
Gap depth	X	X	X
Water width	X	X	X
Bank slopes	X	X	X
Water velocity	X	X	X
Water depth	X	X	X
Water temperature	X	X	X
Bottom material (USCS soil types)	X	X	X
Sediment concentration			
Stream bank vegetation density	X	X	X
Ice thickness	X	X	X
Ice type	X	X	X
Ice cover, percent	X	X	X
Ice strength	X	X	X
Cultural features			
Roads			
Width	X	X	X
Surface material type	X	X	X
Temperature	X	X	X
Embankment slope	X	X	X
Embankment height	X	X	X
Subgrade material type	X	X	X
Curvature	X	X	X
Surface roughness	X	X	X
Structures			
Height			
Building surface area			
Density			
Material type			
Use			
Roof slope			
Roof material type			
Roof temperature			

(Continued)

Table A2 (Concluded)

Parameters	TRKD	WHLD	ROBOTIC
Climate/weather profile			
Air temperature	X	X	X
Wind velocity			
Wind direction			
Solar radiation			
Precipitation rates (rain, snow, hail)	X	X	X
Lightning rates			X
Water vapor density (absolute humidity)			X
Dew point (relative humidity)			X
Cloud cover			
Barometer pressure			X
Glazing			
Hoar frost			
Freeze-thaw cycles	X	X	X
Ozone level			
Freezing degree days			
Obscurants (natural and BIC)			
Type	X	X	X
Size distribution			X
Refractive index			X
Density	X	X	X

(Sheet 3 of 3)

Table A3

Sensor Systems

Parameters	IR*	MMW*	SEIS*	ACOU*	MAGN*	PRES*	TW*
Topography							
Slope magnitude		X		X			
Slope aspect							
Elevation		X	X	X			X
Microsurface roughness	X	X	X				X
Surface composition							
USCS soil type	X	X	X				
Soil strength						X	
Soil moisture content	X	X				X	
Soil density			X			X	
Soil permeability			X			X	
Soil temperature	X	X					
Soil shear wave velocity			X				
Soil compression wave velocity			X				
Soil layer depth			X				
Depth to water table			X				
Soil reflectivity	X	X					
Soil emissivity	X	X					
Soil specific heat	X	X					
Soil mineral content			X				
Snow depth		X	X			X	X
Snow density		X	X			X	X
Frozen layer depth		X	X			X	
Snow hardness		X				X	
Snow cover, percent	X					X	X
Snow crystal type		X					
Snow temperature gradient	X	X					
Snow roughness	X	X					X
Snow emissivity	X	X					
Snow reflectivity	X	X					
Vegetation							
Type	X	X		X			X
Height				X			X
Density/spacing	X	X		X			X
Canopy closure	X	X					

(Continued)

* IR = Infrared; MMW = Millimetre wave; SEIS = Seismic; ACOU = Acoustic; MAGN = Magnetic; PRES = Pressure; TW = Trip wire.

(Sheet 1 of 3)

Table A3 (Continued)

Parameters	IR*	MMW*	SEIS*	ACOU*	MAGN*	PRES*	TW*
Vegetation (Cont'd)							
Ground cover	X	X					X
Stem diameters							X
Foliage density	X	X		X			
Branch density				X			
Reflectivity	X	X					
Emissivity	X	X					
Absorptivity	X	X					
Hydrologic features							
Gap width	X	X	X				
Gap depth			X				
Water width	X	X	X				
Bank slopes							X
Water velocity				X			
Water depth	X	X			X	X	
Water temperature	X	X					
Bottom material (USCS soil types)	X	X	X			X	
Sediment concentration							
Stream bank vegetation density	X	X		X			X
Ice thickness		X	X				
Ice type	X	X					
Ice cover, percent	X	X					
Ice strength						X	
Cultural features							
Roads							
Width	X	X					
Surface material type	X	X	X			X	
Temperature	X	X		X			
Embankment slope			X				X
Embankment height			X				X
Subgrade material type			X				
Curvature							
Surface roughness	X	X					X
Structures							
Height		X		X			
Building surface area				X			
Density		X		X			
Material type	X	X		X			
Use				X			

(Continued)

Table A3 (Concluded)

Parameters	IR	MMW	SEIS	ACOU	MAGN	PRES	TW
Structures (Cont'd)							
Material type	X	X		X			
Use				X			
Roof slope	X	X					
Roof material type	X	X					
Roof temperature	X	X					
Climate/weather profile							
Air temperature	X			X			
Wind velocity			X	X			
Wind direction			X	X			
Solar radiation	X	X		X			
Precipitation rates (rain, snow, hail)	X	X	X	X		X	
Lightning rates		X	X	X			
Water vapor density (absolute humidity)	X	X		X			
Dew point (relative humidity)	X	X		X			
Cloud cover	X	X					
Barometer pressure				X			
Glazing	X	X					
Hoar frost	X	X	X				
Freeze-thaw cycles	X	X	X				
Ozone level							
Freezing degree days							
Obscurants (natural and BIC)							
Type	X	X		X			
Size distribution	X	X					
Refractive index							
Density	X	X					

Table A4

Bridging Systems

Parameters	Fix*	Float*	Assault*
Topography			
Slope magnitude			
Slope aspect			
Elevation			
Microsurface roughness			
Surface composition			
USCS soil type	X		X
Soil strength	X		X
Soil moisture content	X		X
Soil density	X		X
Soil permeability	X		
Soil temperature			
Soil shear wave velocity			
Soil compression wave velocity			
Soil layer depth	X		X
Depth to water table	X		X
Soil reflectivity			
Soil emissivity			
Soil specific heat			
Soil mineral content			
Snow depth			X
Snow density			
Frozen layer depth			X
Snow hardness			
Snow cover, percent			X
Snow crystal type			
Snow temperature gradient			
Snow roughness			
Snow emissivity			
Snow reflectivity			
Vegetation			
Type			
Height			
Density/spacing			
Canopy closure			
Ground cover			
Stem diameters			

(Continued)

* Fix = Fixed; Float = Floating; Assault = Assault tactical.

Table A4 (Continued)

Parameters	Fix	Float	Assault
Vegetation (Cont'd)			
Foliage density			
Branch density			
Reflectivity			
Emissivity			
Absorptivity			
Hydrologic features			
Gap width	X	X	X
Gap depth	X	X	X
Water width	X	X	X
Bank slopes	X	X	X
Water velocity	X	X	X
Water depth	X	X	X
Water temperature			
Bottom material (USCS soil types)	X	X	X
Sediment concentration			
Stream bank vegetation density			X
Ice thickness		X	X
Ice type		X	X
Ice cover, percent		X	X
Ice strength		X	X
Cultural features			
Roads			
Width			X
Surface material type			X
Temperature			
Embankment slope			
Embankment height			
Subgrade material type			
Curvature			X
Surface roughness			X
Structures			
Height			
Building surface area			
Density			
Material type			
Use			
Roof slope			
Roof material type			
Roof temperature			

(Continued)

Table A4 (Concluded)

Parameters	Fix	Float	Assault
Climate/weather profile			
Air temperature			
Wind velocity			
Wind direction			
Solar radiation			
Precipitation rates (rain, snow, hail)		X	X
Lightning rates			
Water vapor density (absolute humidity)			
Dew point (relative humidity)			
Cloud cover			
Barometer pressure			
Glazing			
Hoar frost			
Freeze-thaw cycles			
Ozone level			
Freezing degree days			X
Obscurants (natural and BIC)			
Type			
Size distribution			
Refractive index			
Density			

Table A5

Munitions Systems

Parameters	PD*	VT*	CHEM*
Topography			
Slope magnitude			
Slope aspect			
Elevation			X
Microsurface roughness		X	
Surface composition			
USCS soil type	X		
Soil strength	X		
Soil moisture content	X		
Soil density	X		
Soil permeability			
Soil temperature			
Soil shear wave velocity			
Soil compression wave velocity			
Soil layer depth			
Depth to water table			
Soil reflectivity			
Soil emissivity			
Soil specific heat			
Soil mineral content			
Snow depth			
Snow density			
Frozen layer depth			
Snow hardness			
Snow cover, percent			
Snow crystal type			
Snow temperature gradient			
Snow roughness			
Snow emissivity			
Snow reflectivity			
Vegetation			
Type			
Height			
Density/spacing			
Canopy closure			
Ground cover			
Stem diameters			

(Continued)

* PD = Point detonating; VT = Variable time; CHEM = Chemical fuse.

(Sheet 1 of 3)

Table A5 (Continued)

Parameters	PD	VT	CHEM
Foliage density			
Branch density			
Reflectivity			
Emissivity			
Absorptivity			
Hydrologic features			
Gap width			
Gap depth			
Water width	X		X
Bank slopes			
Water velocity			
Water depth			
Water temperature			
Bottom material (USCS soil types)			
Sediment concentration			
Stream bank vegetation density		X	X
Ice thickness			
Ice type			
Ice cover, percent			
Ice strength			
Cultural features			
Roads			
Width	X		
Surface material type	X		
Temperature			
Embankment slope	X		
Embankment height		X	
Subgrade material type			
Curvature			
Surface roughness			
Structures			
Height	X	X	X
Building surface area		X	
Density			X
Material type			
Use			
Roof slope	X	X	
Roof material type			
Roof temperature			

(Continued)

Table A5 (Concluded)

Parameters	PD	VT	CHEM
Climate/weather profile			
Air temperature			X
Wind velocity			X
Wind direction			
Solar radiation			X
Precipitation rates (rain, snow, hail)			X
Lightning rates		X	
Water vapor density (absolute humidity)			X
Dew point (relative humidity)			X
Cloud cover			
Barometer pressure			
Glazing			
Hoar frost			
Freeze-thaw cycles			
Ozone level			
Freezing degree days			
Obscurants (natural and BIC)			
Type			X
Size distribution			X
Refractive index			X
Density			X

Table A6

Direct Fire Weapon System

Parameters	Tar Det*	Guid*	Identification Class*
Topography			
Slope magnitude	X		X
Slope aspect			
Elevation	X	X	X
Microsurface roughness			
Surface composition			
USCS soil type			
Soil strength			
Soil moisture content			
Soil density			
Soil permeability			
Soil temperature			
Soil shear wave velocity			
Soil compression wave velocity			
Soil layer depth			
Depth to water table			
Soil reflectivity			
Soil emissivity			
Soil specific heat			
Soil mineral content			
Snow depth			X
Snow density			
Frozen layer depth			
Snow hardness			
Snow cover, percent			
Snow crystal type			
Snow temperature gradient			
Snow roughness			
Snow emissivity			
Snow reflectivity			
Vegetation			
Type	X	X	X
Height	X	X	X
Density/spacing	X	X	X
Canopy closure			
Ground cover			
Stem diameters			

(Continued)

* Tar Det = Target detection; Guid = Guidance; Class = Classification.

Table A6 (Continued)

Parameters	Tar Det	Guid	Identification Class
Vegetation (Cont'd)			
Foliage density			
Branch density			
Reflectivity			
Emissivity			
Absorptivity			
Hydrologic features			
Gap width			
Gap depth			
Water width			
Bank slopes			X
Water velocity			
Water depth			
Water temperature			
Bottom material (USCS soil types)			
Sediment concentration			
Stream bank vegetation density	X	X	X
Ice thickness			
Ice type			
Ice cover, percent			
Ice strength			
Cultural features			
Roads			
Width			
Surface material type			
Temperature			
Embankment slope	X	X	X
Embankment height	X	X	X
Subgrade material type			
Curvature			
Surface roughness			
Structures			
Height	X	X	X
Building surface area	X	X	X
Density	X	X	X
Material type			X
Use			
Roof slope			

(Continued)

Table A6 (Concluded)

Parameters	Tar Det	Guid	Identification Class
Structures (Cont'd)			
Roof material type			
Roof temperature			
Climate/weather profile			
Air temperature			
Wind velocity			
Wind direction			
Solar radiation			X
Precipitation rates (rain, snow, hail)			X
Lightning rates			X
Water vapor density (absolute humidity)			X
Dew point (relative humidity)			X
Cloud cover			
Barometer pressure			
Glazing			
Hoar frost			
Freeze-thaw cycles			
Ozone level			
Freezing degree days			
Obscurants (natural and BIC)			
Type			X
Size distribution			X
Refractive index			X
Density			X

Table A7

Top-Attack Weapon Systems

Parameters	TRKG*	ACQ*	AIM*	WH-FIRE*
Topography				
Slope magnitude			X	X
Slope aspect				
Elevation				
Microsurface roughness				
Surface composition parameters				
USCS soil type	X	X		
Soil strength				
Soil moisture content				
Soil density				
Soil permeability				
Soil temperature	X	X	X	
Soil shear wave velocity				
Soil compression wave velocity				
Soil layer depth				
Depth to water table				
Soil reflectivity	X	X	X	
Soil emissivity	X	X		
Soil specific heat	X	X		
Soil mineral content				
Snow depth	X	X		
Snow density	X	X		
Frozen layer depth				
Snow hardness				
Snow cover, percent	X	X		
Snow crystal type				
Snow temperature gradient	X	X		
Snow roughness				
Snow emissivity	X	X		
Snow reflectivity	X	X		
Vegetation				
Type	X	X		
Height				
Density/spacing	X	X		
Canopy closure	X	X	X	X
Ground cover	X	X	X	

(Continued)

* TRKG = Tracking; ACQ = Acquisition; AIM = Aiming; WH-FIRE = Warhead firing.

Table A7 (Continued)

Parameters	TRKG	ACQ	AIM	WH-FIRE
Vegetation (Cont'd)				
Stem diameters				X
Foliage density	X	X	X	
Branch density	X	X	X	
Reflectivity	X	X		
Emissivity	X	X		
Absorptivity	X	X		
Hydrologic features				
Gap width	X	X		
Gap depth				
Water width	X	X		
Bank slopes	X	X	X	X
Water velocity				
Water depth				
Water temperature	X	X	X	
Bottom material (USCS soil types)				
Sediment concentration				
Stream bank vegetation density	X	X	X	X
Ice thickness				
Ice type	X	X		
Ice cover, percent	X	X		
Ice strength				
Cultural features				
Roads				
Width	X	X	X	X
Surface material type	X	X		
Temperature	X	X		
Embankment slope				
Embankment height				
Subgrade material type				
Curvature				
Surface roughness				
Structures				
Height				X
Building surface area	X	X	X	X
Density	X	X	X	X
Material type	X	X		
Use				
Roof slope	X	X		
Roof material type	X	X		

(Continued)

Table A7 (Concluded)

Parameters	TRKG	ACQ	AIM	WH-FIRE
Structures (Cont'd)				
Roof temperature	X	X		
Climate/weather profile				
Air temperature				
Wind velocity				
Wind direction				
Solar radiation	X	X		
Precipitation rates (rain, snow, hail)	X	X		
Lightning rates				
Water vapor density (absolute humidity)	X	X	X	X
Dew point (relative humidity)	X	X		
Cloud cover				
Barometer pressure	X	X		
Glazing				
Hoar frost				
Freeze-thaw cycles				
Ozone level				
Freezing degree days				
Obscurants (natural and BIC)				
Type	X	X	X	
Size distribution	X	X	X	
Refractive index	X	X	X	
Density	X	X	X	

Table A8

Communication Systems

Parameters	Radio	Microwave	SW*
Topography			
Slope magnitude		X	X
Slope aspect		X	X
Elevation	X	X	X
Microsurface roughness			
Surface composition			
USCS soil type			
Soil strength			
Soil moisture content			
Soil density			
Soil permeability			
Soil temperature			
Soil shear wave velocity			
Soil compression wave velocity			
Soil layer depth			
Depth to water table			
Soil reflectivity			
Soil emissivity			
Soil specific heat			
Soil mineral content			
Snow depth			
Snow density			
Frozen layer depth			
Snow hardness			
Snow cover, percent			
Snow crystal type			
Snow temperature gradient	X		
Snow roughness			
Snow emissivity			
Snow reflectivity			
Vegetation			
Type	X	X	X
Height	X	X	X
Density/spacing	X	X	X
Canopy closure			
Ground cover			
Stem diameters			
Foliage density	X	X	X

(Continued)

* SW = Shortwave.

Table A8 (Continued)

Parameters	Radio	Microwave	SW*
Vegetation (Cont'd)			
Branch density			
Reflectivity			
Emissivity			
Absorptivity			
Hydrologic features			
Gap width			
Gap depth			
Water width			
Bank slopes			
Water velocity			
Water depth			
Water temperature	X	X	X
Bottom material (USCS soil types)			
Sediment concentration			
Stream bank vegetation density			
Ice thickness			
Ice type			
Ice cover, percent			
Ice strength			
Cultural features			
Roads			
Width			
Surface material type			
Temperature	X	X	X
Embankment slope			
Embankment height			
Subgrade material type			
Curvature			
Surface roughness			
Structures			
Height			
Building surface area			
Density			
Material type			
Use			
Roof slope			
Roof material type			
Roof temperature			

(Continued)

Table A8 (Concluded)

Parameters	Radio	Microwave	SW
Climate/weather profile			
Air temperature	X	X	X
Wind velocity	X	X	X
Wind direction	X	X	X
Solar radiation			
Precipitation rates (rain, snow, hail)	X	X	X
Lightning rates	X	X	X
Water vapor density (absolute humidity)	X	X	X
Dew point (relative humidity)	X	X	X
Cloud cover			
Barometer pressure			
Glazing			
Hoar frost			
Freeze-thaw cycles			
Ozone level			
Freezing degree days			
Obscurants (natural and BIC)			
Type	X	X	X
Size distribution	X	X	X
Refractive index			
Density			

(Sheet 3 of 3)

Table A9

Air Systems

Parameters	Fixed*	Rotary*
Topography		
Slope magnitude		
Slope aspect	X	X
Elevation	X	X
Microsurface roughness		
Surface composition		
USCS soil type	X	X
Soil strength	X	X
Soil moisture content		
Soil density		
Soil permeability		
Soil temperature		
Soil shear wave velocity		
Soil compression wave velocity		
Soil layer depth		
Depth to water table		
Soil reflectivity		
Soil emissivity		
Soil specific heat		
Soil mineral content		
Snow depth		
Snow density		
Frozen layer depth		
Snow hardness		
Snow cover, percent		
Snow crystal type		
Snow temperature gradient		
Snow roughness		
Snow emissivity		
Snow reflectivity		
Vegetation		
Type		
Height	X	X
Density/spacing		X
Canopy closure		
Ground cover		
Stem diameters		
Foliage density		

(Continued)

* Fixed = Fixed aircraft; Rotary = Rotary aircraft.

Table A9 (Continued)

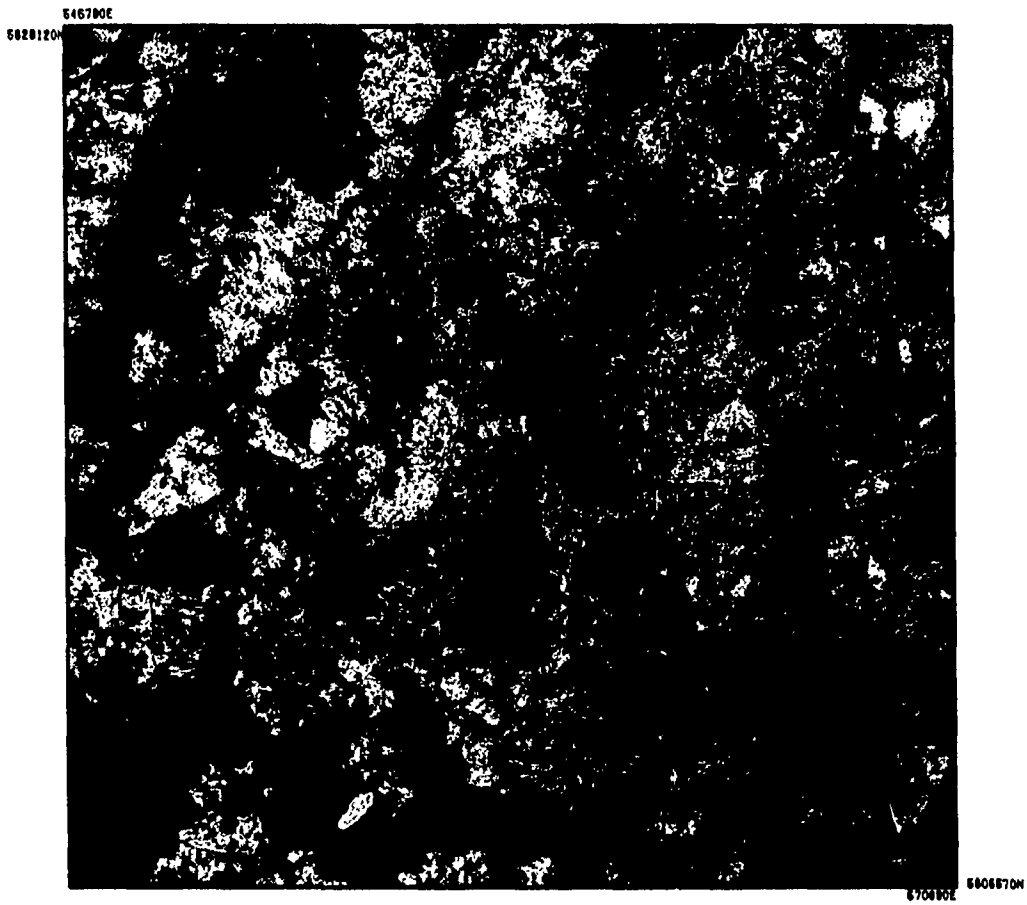
Parameters	Fixed	Rotary
Vegetation (Cont'd)		
Branch density		
Reflectivity		
Emissivity		
Absorptivity		
Hydrologic features		
Gap width		
Gap depth		
Water width		
Bank slopes		
Water velocity		
Water depth		
Water temperature		
Bottom material (USCS soil types)		
Sediment concentration		
Stream bank vegetation density		
Ice thickness		
Ice type		
Ice cover, percent		
Ice strength		
Cultural features		
Roads		
Width	X	X
Surface material type	X	X
Temperature		
Embankment slope		
Embankment height	X	X
Subgrade material type		
Curvature	X	
Surface roughness		
Structures		
Height	X	X
Building surface area	X	X
Density	X	X
Material type		
Use		
Roof slope		
Roof material type		
Roof temperature		

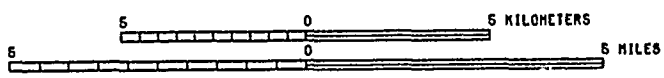
(Continued)

Table A9 (Concluded)

Parameters	Fixed	Rotary
Climate/weather profile		
Air temperature	X	X
Wind velocity	X	X
Wind direction	X	X
Solar radiation		
Precipitation rates (rain, snow, hail)	X	X
Lightning rates	X	X
Water vapor density (absolute humidity)		
Dew point (relative humidity)		
Cloud cover	X	X
Barometer pressure		
Glazing		
Hoar frost		
Freeze-thaw cycles		
Ozone level		
Freezing degree days		
Obscurants (natural and BIC)		
Type	X	X
Size distribution	X	X
Refractive index		
Density	X	X

(Sheet 3 of 3)





THE 10 OCTOBER 1987 THEMATIC MAPPER FALSE COLOR COMPOSITE IMAGE FOR THE HUNFELD QUADRANGLE AREA. BAND ASSIGNMENT IS 2, 3, 4 (BLUE, GREEN, RED)

PLATE 1

546770,5628130

GM
GC
SM
SC
ML
CL
OL
CH
PT
Rock
Urban areas

576770,5605630

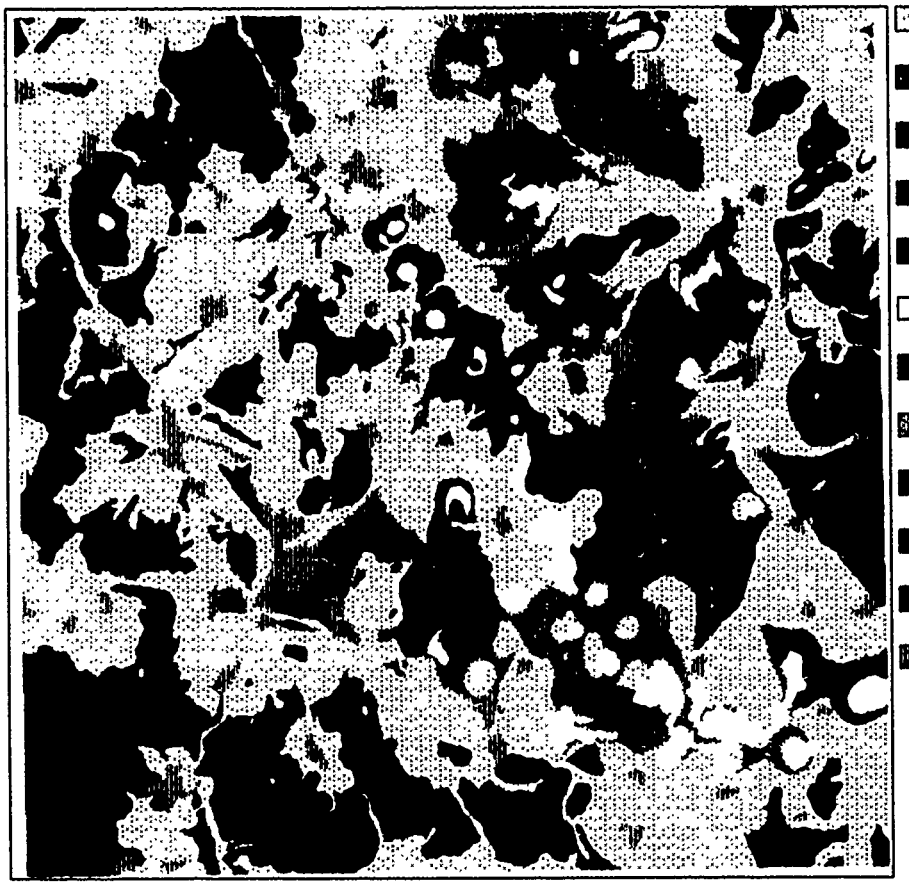
5 0 5 KILOMETERS

5 0 5 MILES

SURFACE SOIL TYPES
HUNFELD QUADRANGLE AREA

PLATE 2

546778,5628130



0 - 75
76 - 120
121 - 150
151 - 180
181 - 240
241 - 300
301 - 360
361 - 450
451 - 560
561 - 760
> 760
Urban areas

578778,5685630

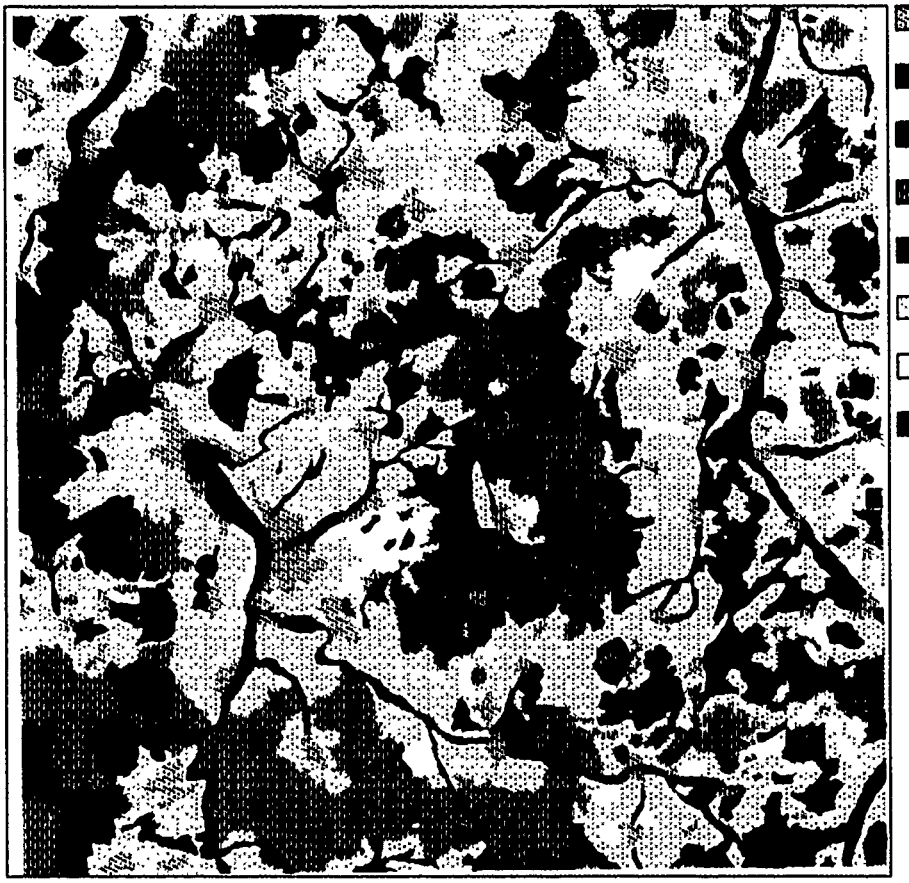
5 0 5 KILOMETERS

5 0 5 MILES

SHEAR WAVE VELOCITIES (METRES/SECOND)
SURFACE SOIL LAYER 1
HUNFELD QUADRANGLE AREA

PLATE 3

546778,562813B



- Urban areas
- Deciduous forest
- Coniferous forest
- Mixed forest
- Meadows/pastures
- Croplands
- Other agriculture
- Marsh vegetation

578778,5685638

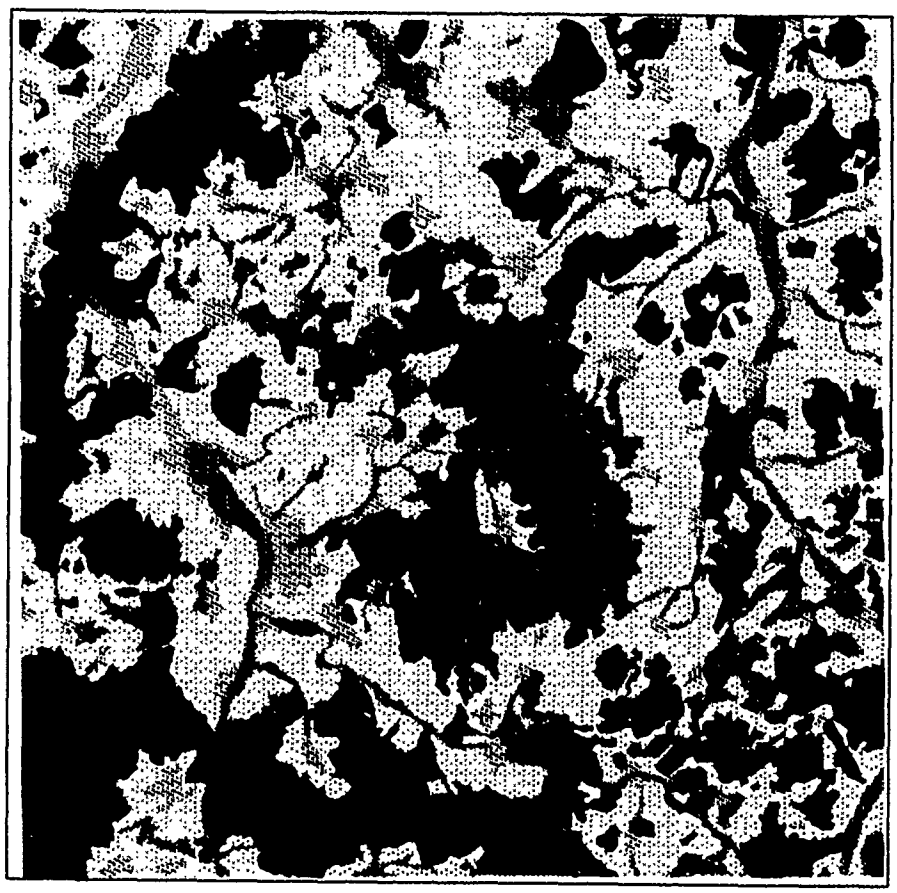
5 0 5 KILOMETERS

5 0 5 MILES

VEGETATION TYPES
HUNFELD QUADRANGLE AREA

PLATE 4

546778,5628130



Urban areas
0.1 - 0.5
>0.5 - 2.0
>2.0 - 5.0
>5.0 - 12.0
>12.0 - 18.0
>18.0 - 24.0
>24.0 - 30.0
>30.0

578778,5685638

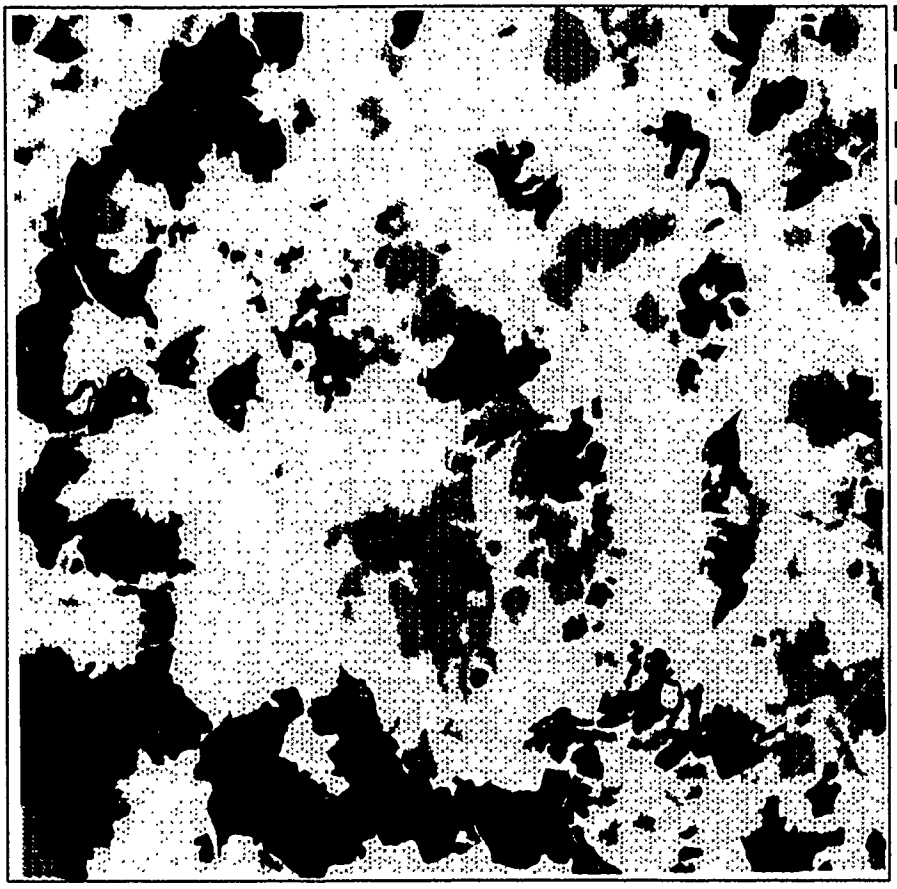
5 0 5 KILOMETERS

5 0 5 MILES

VEGETATION HEIGHTS (METRES)
HUNFELD QUADRANGLE AREA

PLATE 5

546778,5628138



< 25
25 - 50
> 50 - 75
> 75
Non-forested

578778,5685638

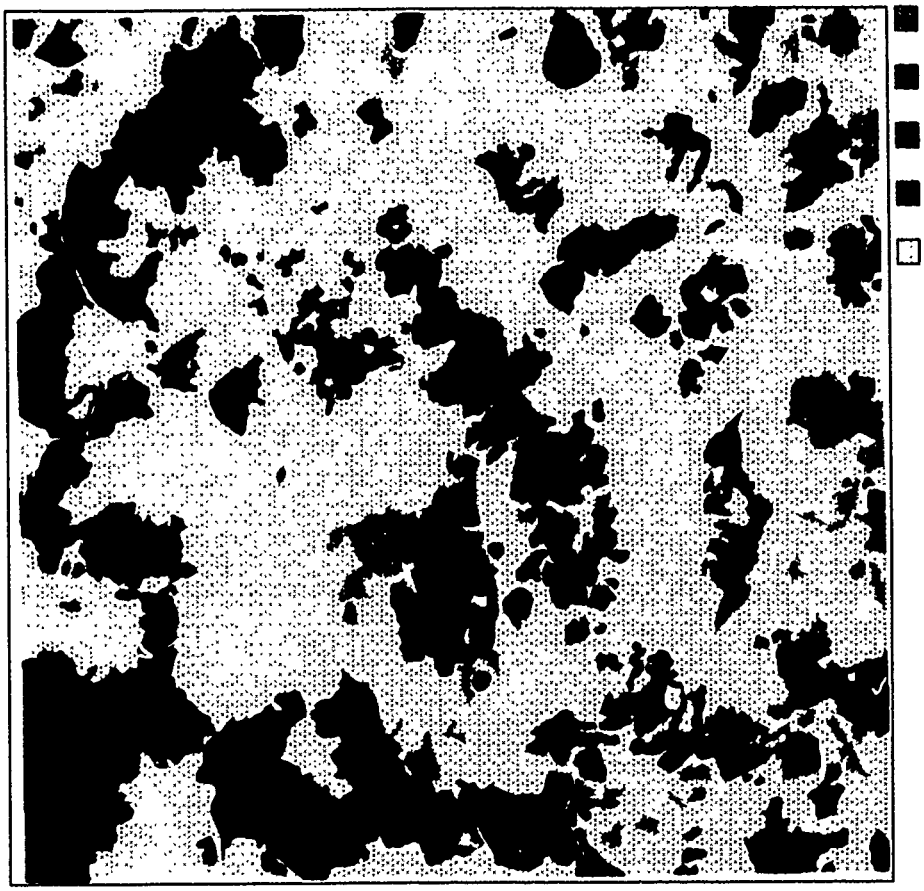
5 0 5 KILOMETERS

5 0 5 MILES

MINIMUM PERCENT CANOPY CLOSURES
HUNFELD QUADRANGLE AREA

PLATE 6

546778,5628130



< 25
25 - 50
> 50 - 75
> 75
Non-forested

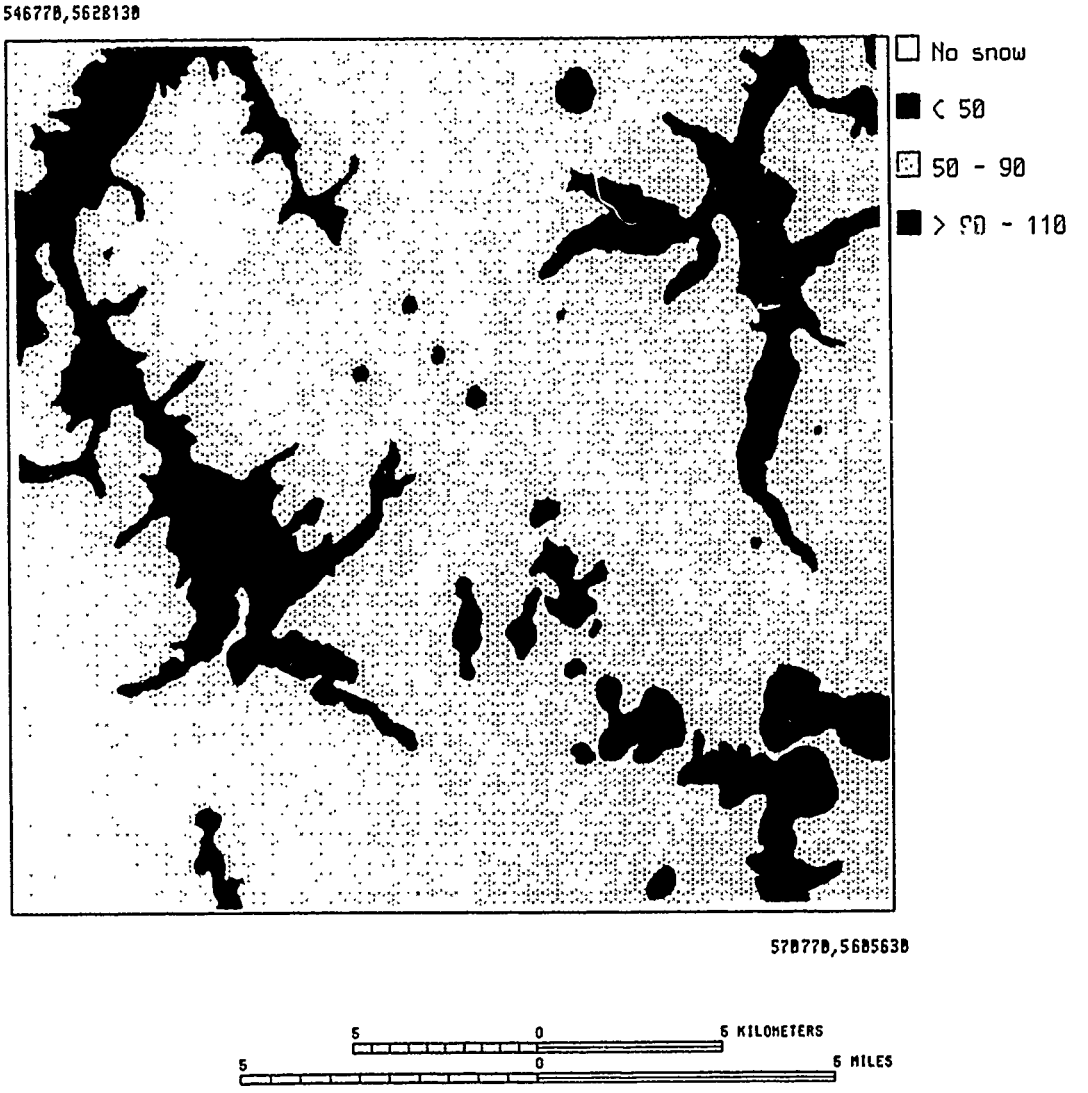
578778,5685630

5 0 5 KILOMETERS

5 0 5 MILES

MAXIMUM PERCENT CANOPY CLOSURES
HUNFELD QUADRANGLE AREA

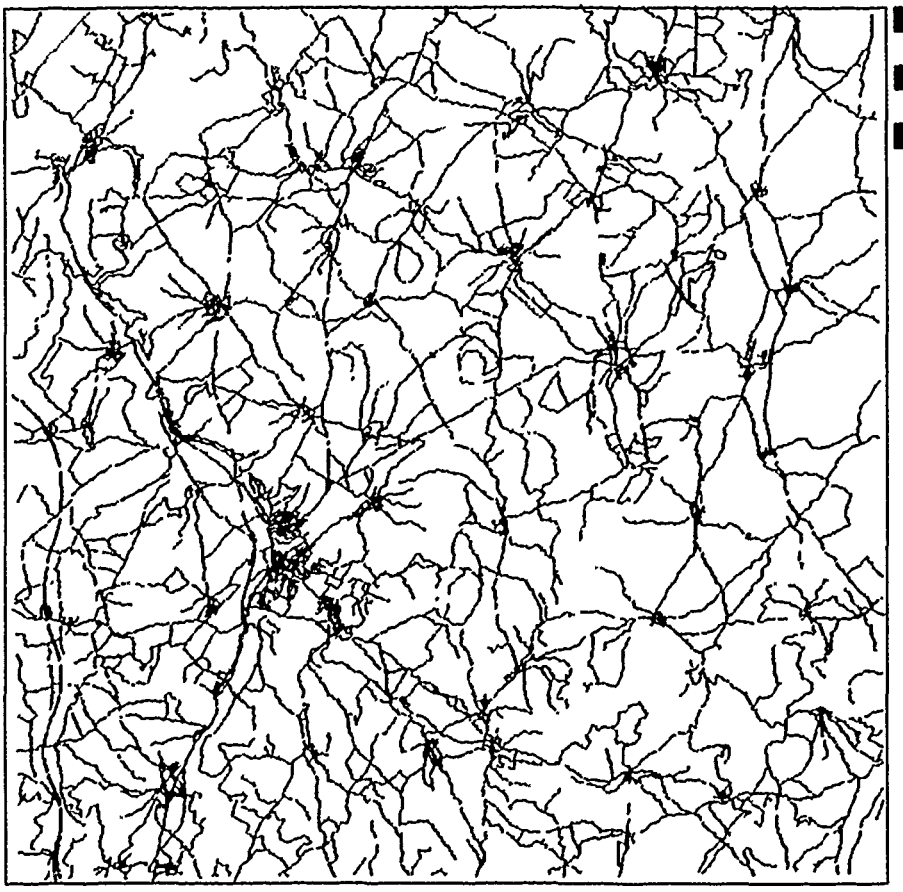
PLATE 7



AVERAGE ANNUAL SNOWFALL (CENTIMETRES)
HUNFELD QUADRANGLE AREA

PLATE 8

546778,5628138



Autobahn

Primary roads

Secondary roads

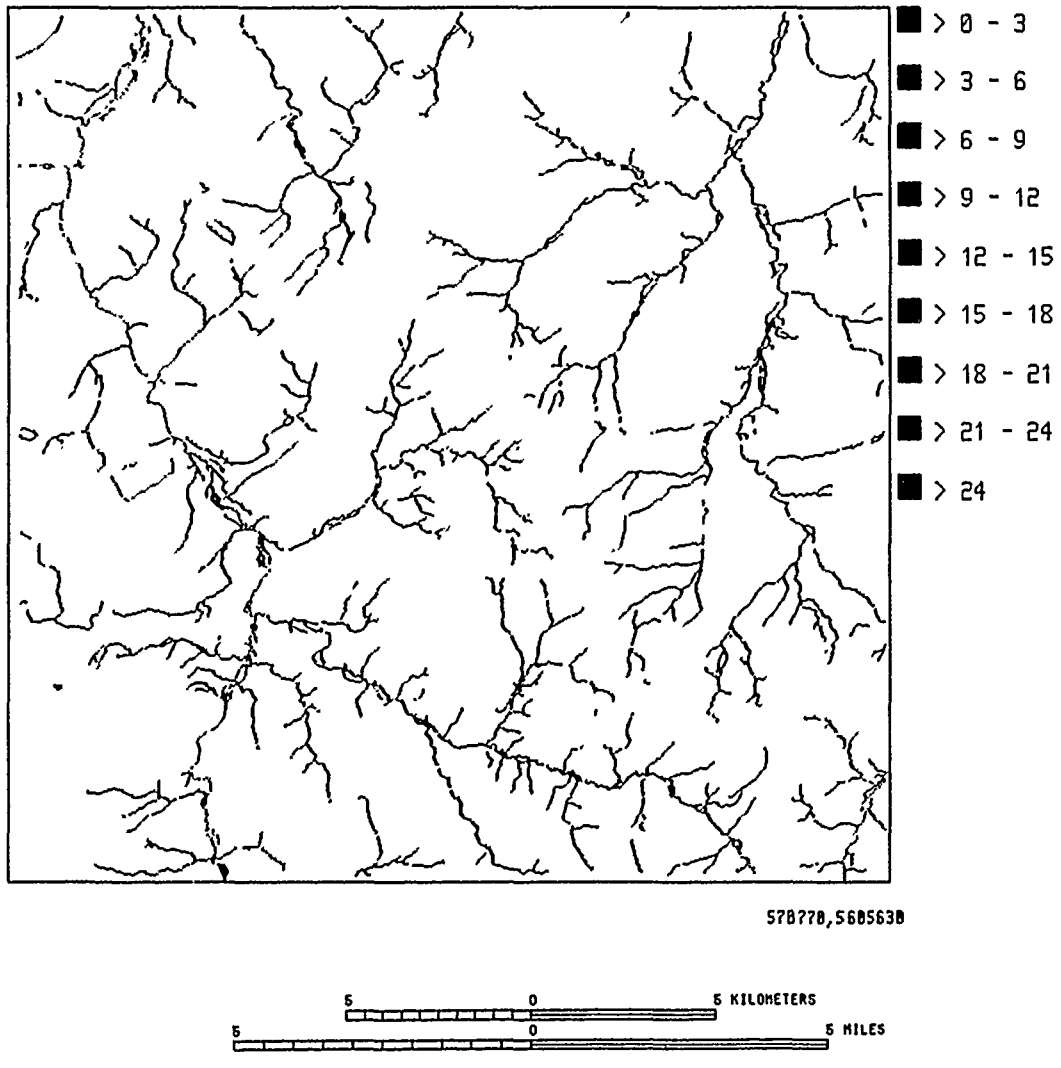
578778,5685638

5 0 5 KILOMETERS

5 0 5 MILES

ROAD NETWORK AND TYPES
HUNFELD QUADRANGLE AREA

PLATE 9



STREAM GAP WIDTH RANGES (METRES)
HUNFELD QUADRANGLE AREA

PLATE 10